BULLETIN

OF THE

GEOLOGICAL SOCIETY

OF

AMERICA

VOL. 29

JOSEPH STANLEY-BROWN, Editor

NEW YORK
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1918

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Geol.

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(22 plates; 67 figures)

PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA

Regular Publications

The Society issues annually, in four quarterly parts, a single serial octavo publication entitled Bulletin of the Geological Society of America, the edition being 700 copies. A smali supply of authors' separates of the longer articles is kept for sale by the Secretary at the prices quoted in each volume.

The Bulletin is sold at the uniform price of ten dollars ($10.00) per volume, with a discount of twenty-five (25) per cent to Fellows of the Society, persons residing elsewhere than in North America, and public and institutional libraries; carriage extra. Subscriptions are payable in advance. Regular subscribers within the United States of America and its possessions receive their parts, postage paid, as issued. Forty (40) cents per volume must be added to the subscription price to cover postage to other countries in the Postal Union.

The price of the index to volumes 1-10 is $2.25 and of the index to volumes 11-20 is $3.50; carriage extra. No reduction is made to dealers. Orders should be addressed to the Secretary, whose address is care of the American Museum of Natural History, New York, N. Y., and drafts and money orders should be made payable to *The Geological Society of America.*

Description of the Published Volumes

Volumes.	Pages.	Plates.	Figures.
Vol. 1, 1889	593 + xii	13	51
Vol. 2, 1890	622 + xiv	23	63
Vol. 3, 1891	541 + xi	17	72
Vol. 4, 1892	458 + xi	10	55
Vol. 5, 1893	655 + xii	21	43
Vol. 6, 1894	528 + x	27	40
Vol. 7, 1895	558 + x	24	61
Vol. 8, 1896	446 + x	51	29
Vol. 9, 1897	460 + x	29	49
Vol. 10, 1898	534 + xii	54	83
Index to volumes 1–10	209	..	..
Vol. 11, 1899	651 + xii	58	37
Vol. 12, 1900	538 + xii	45	28
Vol. 13, 1901	583 + xii	58	47
Vol. 14, 1902	609 + xii	65	43
Vol. 15, 1903	636 + x	59	16
Vol. 16, 1904	636 + xii	94	74
Vol. 17, 1905	785 + xiv	84	96
Vol. 18, 1906	717 + xii	74	59
Vol. 19, 1907	617 + x	41	31
Vol. 20, 1908	749 + xiv	111	35
Index to volumes 11–20	422	..	..
Vol. 21, 1909	823 + xvi	54	109
Vol. 22, 1910	747 + xii	31	66
Vol. 23, 1911	758 + xvi	43	44
Vol. 24, 1912	737 + xviii	36	60
Vol. 25, 1913	802 + xviii	28	47
Vol. 26, 1914	504 + xxi	27	41
Vol. 27, 1915	739 + xviii	30	55
Vol. 28, 1916	1005 + xxii	48	102
Vol. 29, 1917	679 + xix	22	67

Parts of Volume 29

	Pages.	Plates.	Figures.	Price to Fellows.	Price to Public.
Number 1	1–186	1– 8	--	$2.10	$3.05
Number 2	187–374	9–19	15	2.20	3.30
Number 3	375–600	–22	51	2.35	3.50
Number 4 *	601–666	....	1	.95	1.45

Reprints from Volume 29

Reprints.	Pages.	Plates.	Figures.	Price to Fellows.	Price to Public.
Proceedings of the Thirtieth Annual Meeting of the Geological Society of America, held at Saint Louis, Missouri, December 27, 28, and 29, 1917. Edmund Otis Hovey, *Secretary*	1–118	1–8	....	$1.45	$2.15
Proceedings of the Ninth Annual Meeting of the Paleontological Society, held at Pittsburgh, Pennsylvania, December 31, 1917, and January 1 and 2, 1918. R. S. Bassler, *Secretary* †	119–160	....	....	.40	.60
Minutes of the Eighth Annual Meeting of the Pacific Coast Section of the Paleontological Society. Chester Stock, *Secretary*	160–166	....	....	.10	.15
Experiment in geology. Frank D. Adams	167–186	....	....	.20	.30
Post-Glacial uplift of Northeastern America. H. L. Fairchild	187–234	9–17	1	.75	1.10
Explanation of the abandoned beaches about the south end of Lake Michigan. G. F. Wright	235–244	....	1– 3	.10	.15
Age of the American Morrison and East African Tendaguru formations. Charles Schuchert†	245–280	....	....	.35	.55
Meganos group, a newly recognized division in the Eocene of California. B. L. Clark†	281–296	....	1– 2	.15	.25
Marine Oligocene of the west coast of North America. B. L. Clark and Ralph Arnold†	297–308	....	1– 3	.10	.15
Amsden formation of the east slope of the Wind River Mountains of Wyoming and its fauna. E. B. Branson and D. K. Greger	309–326	18–19	1	.25	.35
Stratigraphy of the New York Clinton. G. H. Chadwick	327–368	....	1– 5	.40	.65
Scope and significance of Paleo-ecology. F. E. Clements	369–374	....	....	.10	.15
Precambrian sedimentary rocks in the highlands of eastern Pennsylvania. E. T. Wherry	375–392	....	1–14	.20	.30

* Preliminary pages and index are distributed with number 4.

† Under the brochure heading is printed Proceedings of the Paleontological Society.

Reprints.	Pages.	Plates.	Figures.	Price to Fellows.	Price to Public.
Fluorspar in the Ordovician limestone of Wisconsin. R. M. Bagg.	393–398	20	1	$0.10	$0.15
Adirondack anorthosite. W. J. Miller	399–462	....	1– 3	.65	.95
Field relations of litchfieldite and soda-syenites of Litchfield, Maine. R. A. Daly	463–470	....	1– 2	.10	.15
Separation of salt from saline water and mud. E. W. Kindle	471–488	....	1–12	.20	.30
Subsidence of reef-encircled islands. W. M. Davis	489–574	....	1–17	.85	1.25
Ages of peneplains of the Appalachian province. E. W. Shaw	575–586	....	....	.10	.15
Oolites in shale and their origin. W. A. Tarr	587–600	21–22	1– 2	.20	.30
Mesozoic history of Mexico, Central America, and the West Indies. T. W. Stanton†	601–606	....	....	.10	.15
Relations between the Mesozoic floras of North and South America. F. H. Knowlton†	607–614	....	....	.10	.15
Geologic history of Central America and the West Indies during Cenozoic time. T. W. Vaughan†	615–630	....	....	.15	.25
Paleogeographic significance of the Cenozoic floras of equatorial America and the adjacent regions. E. W. Berry†	631–636	....	....	.10	.15
Age of certain plant-bearing beds and associated marine formations in South America. E. W. Berry†	637–648	....	1	.10	.15
Bearing of the distribution of the existing flora of Central America and the Antilles on former land connections. Wm. Trelease†	649–656	....	....	.10	.15
Affinities and origin of the Antillean mammals. W. D. Matthew†	657–666	....	....	.10	.15

† Under the brochure heading is printed Proceedings of the Paleontological Society.

Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued wholly or in part under its auspices. Each author of a memoir receives 30 copies without cost, and is permitted to order any additional number at a slight advance on cost of paper and presswork; and these reprints are identical with those of the editions issued and distributed by the Society; but the cover bears only the title of the paper, the author's name, and the statement [Reprinted from the Bulletin of the Geological Society of America, vol. —, pp. —, pl. — (Date)]. Contributors to the Proceedings and "Abstracts of Papers" are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the reprints issued by the Society.

The following separates of parts of volume 29 have been issued:

Regular Editions

Pages	167–186,		140 copies.	March	31, 1918
"	187–234,	plates 9–17,	140 "	June	30, 1918
"	235–244,		240 "	"	30, 1918
"	245–280,*†		415 "	"	30, 1918
"	281–296,*†		175 "	"	30, 1918
"	297-308,*†		265 "	"	30, 1918
"	309–326,	plates 18–19,	140 "	"	30, 1918
"	327–368,		240 "	"	30, 1918
"	369–374,		290 "	"	30, 1918
"	375–392,		90 "	September	30, 1918
"	393–398,	plate 20,	90 "	"	30, 1918
"	399–462,		90 "	"	30, 1918
"	463–470,		40 "	"	30, 1918
"	471–488,		115 "	"	30, 1918
"	489–574,		60 "	"	30, 1918
"	575–586,		40 "	"	30, 1918
"	587–600,	plates 21–22,	140 "	"	30, 1918
"	601–606,*†		40 "	December,	30, 1918
"	607–614,*†		40 "	"	30, 1918
"	615–630,*†		140 "	"	30, 1918
"	631–636,*†		40 "	"	30, 1918
"	637–648,*†		40 "	"	30, 1918
"	649–656,*†		110 "	"	30, 1918
"	657–666,*†		140 "	"	30, 1918

Special Editions‡

Pages	13– 17,	plate 1,	240 copies.	March	31, 1918
"	17– 20,	" 2,	40 "	"	31, 1918
"	21– 29	" 3,	140 "	"	31, 1918
"	29– 35,	" 4,	90 "	"	31, 1918
"	35– 48,	" 5,	90 "	"	31, 1918
"	48– 55,	" 6,	90 "	"	31, 1918
"	55– 64,	" 7,	90 "	"	31, 1918
"	65– 70,	" 8,	90 "	"	31, 1918
"	107–118,		140 "	"	31, 1918
"	119–166,		215 "	"	31, 1918
"	131–133,		340 "	"	31, 1918
"	133–137,		340 "	"	31, 1918

*** Bearing on the cover**

Proceedings of the Paleontological Society.

[Reprinted from the Bulletin of the Geological Society of America, vol. ——, pp. ——, pls. ——, (Date)].

† Under the brochure heading is printed Proceedings of the Paleontological Society.

‡ Bearing imprint [From Bull. Geol. Soc. Am., Vol. 28, 1916].

CORRECTIONS AND INSERTIONS

All contributors to volume 29 have been invited to send corrections and insertions to be made in their papers, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 239, line 9 from bottom, *insert* comma after word "interior"
" 243, line 14 from bottom, *for* "stretches" *read* scratches
" 281, line 3 from bottom, *for* "50 degrees" *read* 15 degrees
" 288, line 7 from top, *for* "50 degrees" *read* 15 degrees
" 294, line 15 from bottom, *for* "Calabasis" *read* Calabasar
" 295, line 16 from top, *for* "Calabasis" *read* Calabasar
" 327, line 5 from top, *after* "Presented" *insert* by title.

NOTE.—This paper is a subdivision of the paper by the same author entitled "Further studies in the New York Siluric," an abstract of which is on page 92.

Page 329. A remeasurement recently made of the section at Rochester gives:

	Feet	Inches
Irondequoit limestone	18	4
Williamson shale	5	8
Sodus shale	13	4
Reynales limestone	15	3
Furnaceville iron ore	1	0
Bear Creek (?) beds	2	10
Maplewood shale	18	0
Thorold (?) sandstone	3	2
Grimsby red sandstone	53	0

The Medina base rests on eroded, thrust-faulted Queenston.

Page 339, *insert* reference to Bulletin 69, New York State Museum: pp. 1167-1169 (Hartnagel) for section on Wheelocks Creek, tributary to Moyer Creek.
" 342, line 1 from top, *for* "*Leptodesma rhomboidea*" *read Leptodesma rhomboideum*
" 343, line 6 from top, *for* "*Palæoglossa*" *read Palæoglossa*
" 344, line 2 from top, *for* "probably" *read* possibly
" 347, *insert* at bottom of page the following: The thin interleaved limestones in the supposed Wolcott shale above the oolitic ore at Clinton carry:

Palæocyclus rotuloides (abundant)
Acanthoclema asperum?
Leptæna rhomboidalis
Plectambonites elegantulus?
Camarotœchia neglecta?
Atrypa reticularis
Crinoids
Dalmanites aff. *limulurus* (nov. ?)

Page 348, line 2 from bottom, *for* "*rhomboidea*" *read rhomboideum*

" 350, *insert* at bottom of the page the following: *Palæocyclus rotuloides*, described from Ruddock's quarry (3: 43), which Vanuxem (3: 86) puts above the upper ore bed, proves to come from above the *lower* ore. This change probably carries with it the other species described from Ruddock's—*Conostichus circulus*, *Aristophycus?* sp., and *Lingula tæniola*.

Rafinesquina clintoni should be queried in this list.

" 352, line 26 from top, *Cyrtia meta* is probably correctly *C. bialveata* (Conrad)

" 363, lines 4 and 11 from top, *for* "*rhomboidea*" *read rhomboideum*

" 363, line 20 from top, *Lingula tæniola* may be lower Clinton (Wolcott) after all; see preceding. *Palæocyclus rotuloides* becomes lower Clinton also.

" 367, at top of page, *insert Cyrtia bialveata* (*Delthyris bialveata* Conrad; *Spirifera meta* Hall)

" 368, line 15 from top, add: New York State Museum.

" 464, line 3 from bottom, *for* "Scale, 1: —" *read* Scale, 1: 62500

BULLETIN

OF THE

Geological Society of America

VOLUME 29 NUMBER 1

MARCH, 1918

JOSEPH STANLEY-BROWN, EDITOR

PUBLISHED BY THE SOCIETY
MARCH, JUNE, SEPTEMBER, AND DECEMBER

CONTENTS

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

Subscription, $10 per year; with discount of 25 per cent to institutions and libraries and to individuals residing elsewhere than in North America. Postage to foreign countries in the postal union, forty (40) cents extra.

Communications should be addressed to The Geological Society of America, care of 420 11th Street N. W., Washington, D. C., or 77th Street and Central Park, West, New York City.

NOTICE.—In accordance with the rules established by Council, claims for non-receipt of the preceding part of the Bulletin must be sent to the Secretary of the Society within three months of the date of the receipt of this number in order to be filled gratis.

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PRESS OF JUDD & DETWEILER, INC., WASHINGTON, D. C.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 29, PP. 1-118, PLS. 1-8 MARCH 31, 1918

PROCEEDINGS OF THE THIRTIETH ANNUAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT SAINT LOUIS, MISSOURI, DECEMBER 27, 28, AND 29, 1917.

EDMUND OTIS HOVEY, *Secretary*

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Session of Thursday, December 27

The first general session of the Society was called to order at 9.40 o'clock a. m., Thursday, December 27, at the Planters' Hotel, Saint Louis, Missouri, by President Frank D. Adams.

The report of the Council for the year ending November 30, 1917, was presented as follows:

REPORT OF THE COUNCIL

To the Geological Society of America, in thirtieth annual meeting assembled:

The regular annual meeting of the Council was held at Albany, N. Y., in connection with the meeting of the Society, December 27-29, 1916. A special meeting was held at New York, N. Y., February 21, 1917.

The details of administration for the twenty-ninth year of the existence of the Society are given in the following reports of the officers:

Secretary's Report

To the Council of the Geological Society of America:

Secretaryship.—During the absence of the Secretary the duties of the office were efficiently discharged by Charles P. Berkey, Secretary *pro tempore.* The Secretary resumed office on September 1.

Meetings.—The proceedings of the annual general meeting of the Society, held at Albany, N. Y., December 27-29, 1916, have been recorded on pages 1-176, and of the Paleontological Society on pages 189-234, volume 28, of the Bulletin.

Membership.—During the past year the Society has lost eight Fellows by death—Robert Bell, Amos P. Brown, D. D. Cairnes, William Bullock Clark, Charles W. Drysdale, Arnold Hague, Robert H. Loughridge, and H. M. Seely.[1] The names of the twenty-eight Fellows who have completed their membership since their election at the Albany meeting have been added to the list. The present enrollment of the Society is: Correspondents, 10; Fellows, 395; total, 405. Eighteen candidates for Fellowship are before the Society for election and several applications are under consideration by the Council.

Distribution of Bulletin.—There have been received during the year 3 new subscriptions to the Bulletin. The number of volumes sent out to subscribers is now 128. Five volumes are distributed *gratis* to the Library of Congress, the American Museum of Natural History, and the government geological surveys of the United States, Canada, and Mexico.

The irregular distribution of the Bulletin during the past year has been as follows: Complete volumes sold to the public, 61; sent out to supply delinquents, 6; brochures sold to Fellows, 10; sold to the public, 55; sent out to supply deficiencies, 17, and delinquents, 68. Index to volumes 1-10 sold to the public, 4; to volumes 11-20 sold to the public, 3.

Bulletin sales.—The receipts from subscriptions to and sales of the Bulletin during the past year are shown in the following table:

[1] Since the closing of the fiscal year to which this report refers, one Fellow, Albert H. Purdue, has died.

Bulletin Sales, December 1, 1916–November 30, 1917

	Complete volumes.			Brochures and parts.			Grand total.
	Fellows.	Public.	Total.	Fellows.	Public.	Total.	
Volume 1	....	$12.50	$12.50	....	$1.65	$1.65	$14.15
Volume 2	....	12.50	12.50	....	....	....	12.50
Volume 3	....	12.50	12.50	....	....	....	12.50
Volume 4	....	12.50	12.50	....	1.00	1.00	13.50
Volume 5	....	12.50	12.50	....	.80	.80	13.30
Volume 6	....	12.50	12.50	....	....	....	12.50
Volume 7	....	12.50	12.50	....	....	....	12.50
Volume 8	....	12.50	12.50	....	....	....	12.50
Volume 9	....	12.50	12.50	....	....	....	12.50
Volume 10	....	12.50	12.50	....	....	....	12.50
Volume 11	....	12.50	12.50	....	.75	.75	13.25
Volume 12	....	12.50	12.50	....	....	....	12.50
Volume 13	....	12.50	12.50	....	....	....	12.50
Volume 14	....	12.50	12.50	....	1.50	1.50	14.00
Volume 15	....	12.50	12.50	....	1.80	1.80	14.30
Volume 16	....	27.50	27.50	....	....	....	27.50
Volume 17	....	12.50	12.50	$0.25	1.80	2.05	14.55
Volume 18	....	12.50	12.50	2.10	1.80	3.90	16.40
Volume 19	....	20.00	20.00	....	.40	.40	20.40
Volume 20	....	27.50	27.50	....	3.90	3.90	31.40
Volume 21	....	20.00	20.00	....	3.10	3.10	23.10
Volume 22	....	20.00	20.00	....	9.15	9.15	29.15
Volume 23	....	15.00	15.00	....	7.20	7.20	22.20
Volume 24	....	15.00	15.00	....	4.95	4.95	19.95
Volume 25	....	15.00	15.00	....	2.45	2.45	17.45
Volume 26	....	7.50	7.50	1.70	4.20	5.90	13.40
Volume 27	....	22.50	22.50	....	16.95	16.95	39.45
Volume 28	....	825.00	825.00	.90	1.95	2.85	827.85
Volume 29	....	127.50	127.50	....	....	....	127.50
Total	....	$1,355.00	$1,355.00	$4.95	$65.35	$70.30	$1,425.30
Index 1–10	....	9.00	9.00	....	....	....	9.00
Index 11–20	....	10.50	10.50	....	....	....	10.50
Total	....	$1,374.50	$1,374.50	$4.95	$65.35	$70.30	$1,444.80

Receipts for the fiscal year	$1,444.80
Previously reported	20,610.19
Total receipts to date	$22,054.99
Charged on 1917 account, but not yet received	101.85
Total sales to date	$22,156.84

Expenses.—The following table gives the cost of administration and of Bulletin distribution during the past year:

EXPENDITURE OF SECRETARY'S OFFICE DURING THE FISCAL YEAR ENDING NOVEMBER 30, 1917

Account of Administration

Postage	$87.42	
Car fare	1.85	
Printing	253.25	
Messenger service	1.00	
Expense	2.82	
Telephone	6.95	
Travel	1.80	
Typewriter supplies	1.50	
Telegrams	23.22	
Clerical help (Albany)	14.50	
Miscellaneous	13.75	
Exchange on checks	.30	
Total		$408.36

Account of Bulletin

Envelopes	$51.54	
Postage	15.97	
Express	27.91	
Exchange on checks	1.10	
Notary fee	.25	
Car fare	2.20	
Addressograph plates	1.53	
Addressing envelopes	1.00	
Rubber stamps	1.60	
Telegrams	.55	
Storage of paper	24.85	
Total		128.48
Grand total		$536.84

Respectfully submitted,

EDMUND OTIS HOVEY,
Secretary.

TREASURER'S REPORT

To the Council of the Geological Society of America:

The Treasurer herewith submits his annual report for the year ending November 30, 1917.

The membership of the Society at the present time is 395, of whom 303 pay annual dues. Twenty-nine new members were elected at the last

annual meeting, 28 of whom qualified, one having secured the consent of the Council to defer his entering until later. There have been 8 deaths during the year, one a Life Member. There was one Life Commutation, making the present list of life members number 92. Twenty-three members are delinquent in the payment of dues—2 for 6 years, 1 for 4 years, 4 for 3 years, 3 for 2 years—and are therefore liable to be dropped from the roll, and 13 for 1 year.

RECEIPTS

Balance in the treasury, December 1, 1916		$247.46	
Fellowship fees, 1914 (1)	$10.00		
1915 (3)	30.00		
1916 (7)	70.00		
1917 (285)	2,850.00		
		2,960.00	
Initiation fees (28)		280.00	
Life commutation (1)		150.00	
Interest from investments (see list of securities)		1,110.00	
Interest on deposit in Baltimore Trust Company		54.70	
Collection charges added to checks		1.25	
Received from Secretary:			
Sales of publications	$1,444.80		
Author's corrections	4.50		
Postage	8.44		
		1,457.74	
			$6,261.15

EXPENDITURES

Secretary's office:			
Administration	$408.36		
Bulletin	128.48		
Salary	1,000.00		
		$1,536.84	
Treasurer's office:			
Postage, bond, safe-deposit box	$40.00		
Clerk	100.00		
		140.00	
Publication of Bulletin:			
Printing	$1,700.07		
Engraving	529.46		
Editor's allowance	250.00		
		2,479.53	
Contribution to expenses of chairman of Geology and Paleontology Committee of National Research Council		150.00	
Balance in Baltimore Trust Company, December 1, 1917		1,954.78	
			$6,261.15

LIST OF SECURITIES

Bonds

Par

$2,000. Texas and Pacific Railway Company 1st Mortgage 5's. Due June 1, 2000 (Nos. 11915 and 20892).

1,000. St. Louis and San Francisco Railroad Company Equipment 5's. Due February 1, 1919 (No. 1171).

2,000. Fairmont and Clarksburg Traction Company 1st Mortgage 5's. Due October 1, 1938 (Nos. 29 and 30).

3,000. Chicago Railways Company 1st Mortgage 5's. Due February 1, 1927 (Nos. 20750, 20751, and 45871).

2,000. Southern Bell Telephone and Telegraph Company 1st Mortgage 5's. Due January 1, 1941 (Nos. M13217 and M13218).

3,000. United States Steel Corporation 2d Mortgage 5's. Due April 1, 1963 (Nos. 2964, 2974, and 2975).

2,000. Consolidation Coal Company 1st and Refunding Mortgage 40-year Sinking Fund 5's. Due December 1, 1950 (Nos. 11850 and 11851).

2,000. American Agricultural Chemical Company 1st Mortgage 5's. Due October 1, 1928 (Nos. 5834 and 6356).

Stocks

10 shares of the capital stock of the Iowa Apartment House Company.
40 shares of the capital stock of the Ontario Apartment House Company.

Respectfully submitted,

EDWARD B. MATHEWS,
Acting Treasurer.

EDITOR'S REPORT

To the Council of the Geological Society of America:

The Editor submits herewith his annual report. The following tables cover statistical data for the twenty-eight volumes thus far issued:

ANALYSIS OF COSTS OF PUBLICATION

Cost.	Average—Vols. 1-25.	Vol. 26.	Vol. 27.	Vol. 28.
	pp. 759. pls. 42.	pp. 525. pls. 27.	pp. 757. pls. 30.	pp. 1027. pls. 48.
Letter press	$1,807.41	$1,076.22	$1,684.67	$2,128.15
Illustrations	327.04	171.69	378.30	484.37
Paper	....	231.00	416.00	698.00
Total	$2,134.45	$1,478.91	$2,478.97	$3,310.52
Average per page	$2.83	$2.81	$3.27	$3.23

CLASSIFICATION OF SUBJECT-MATTER

Volume.	Areal geology.	Physical geology.	Glacial geology.	Physiographic geology.	Petrographic geology.	Stratigraphic geology.	Paleontologic geology.	Economic geology.	Official matter.	Memorials.	Unclassified.	Total.
	Number of pages.											
1	116	137	92	18	83	44	47	.....	60	4	4	593+xii
2	56	110	60	111	52	168	47	9	55	1	7	662+xiv
3	56	41	44	41	32	158	104	.....	61	15	1	541+xii
4	25	134	38	74	52	52	14	.....	47	32	2	458+xii
5	138	135	70	54	28	51	107	.....	71	14	9	665+xii
6	50	111	75	39	71	99	1	.....	63	25	4	538+x
7	38	77	105	53	40	21	123	4	66	28	13	558+x
8	34	50	98	5	43	67	58	14	79	8	....	446+x
9	2	102	138	.....	44	28	64	16	64	12	....	460+x
10	35	33	96	37	59	62	68	28	84	27	17	534+xiii
11	65	110	21	10	54	31	188	7	71	60	46	651+xii
12	199	39	55	53	24	98	5	5	70	2	....	538+xi
13	125	17	13	24	28	116	42	4	165	32	29	583+xii
14	48	47	48	59	183	118	22	1	80	14	1	609+xi
15	26	124	3	94	36	267	.....	.....	77	17	3	636+x
16	64	111	78	30	102	141	19	.....	67	22	15	636+xiii
17	49	161	41	84	47	294	27	.....	71	9	2	785+xiv
18	16	164	141	5	29	246	5	....	68	40	3	717+xii
19	106	108	29	66	30	155	32	....	56	15	20	617+x
20	43	54	35	29	37	45	303	8	60	3	132	749+xiv
21	72	234	75	48	85	70	106	1	111	11	10	823+xvi
22	23	54	28	28	23	403	74	.....	63	49	1	747+xii
23	75	52	126	108	19	145	134	.....	66	32	1	758+xvi
24	18	57	96	57	49	160	106	23	133	53	3	737+xviii
25	34	211	54	32	156	9	175	.....	108	9	22	802+xviii
26	.....	72	23	11	56	90	148	.....	54	44	6	504+xxi
27	1	59	125	31	146	20	271	2	73	24	5	739+xviii
28	25	273	70	69	78	200	55	39	94	110	14	1005+xxii

Respectfully submitted,

JOSEPH STANLEY-BROWN, *Editor.*

December 20, 1917.

The foregoing report is respectfully submitted,

THE COUNCIL.

December 26, 1917.

On motion, the report was laid on the table as usual for consideration the following day.

ELECTION OF AUDITING COMMITTEE

The Auditing Committee, consisting of Eliot Blackwelder, George F. Kay, and Harry Fielding Reid, was then elected, and the Treasurer's report was referred to it for examination.

ELECTION OF OFFICERS

The Secretary declared the election of officers for 1918 as follows, the ballots having been canvassed and counted by the Council in accordance with the By-Laws:

President:

WHITMAN CROSS, Washington, D. C.

First Vice-President:

BAILEY WILLIS, Stanford University, California.

Second Vice-President:

FRANK LEVERETT, Ann Harbor, Michigan

Third Vice-President:

F. H. KNOWLTON, Washington, D. C.

Secretary:

EDMUND OTIS HOVEY, New York City.

Treasurer:

E. B. MATHEWS, Baltimore, Maryland.

Editor:

JOSEPH STANLEY-BROWN, New York City.

Librarian:

FRANK R. VAN HORN, Cleveland, Ohio.

Councilors (1918-1920):

JOSEPH BARRELL, New Haven, Connecticut.
R. A. DALY, Cambridge, Massachusetts.

ELECTION OF FELLOWS

The Secretary announced the election in due form of the following Fellows, the ballots having been canvassed and counted by the Council:

Paul Bartsch, B. S., M. S., Ph. D., Curator, Division of Marine Invertebrates, United States National Museum.

Norman Levi Bowen, M. A., Ph. D., Petrologist, Geophysical Laboratory, Carnegie Institution of Washington, Washington, D. C.

J. Harlan Bretz, A. B., Ph. D., Assistant Professor of Geology, University of Chicago, Chicago, Illinois.

Lancaster Demorest Burling, B. S., G. E., Invertebrate Paleontologist, Geological Survey of Canada, Ottawa, Canada.

Luiz Filippe Gonzaga de Campos, Director of the Geological Survey of Brazil, Rio de Janeiro, Brazil.

J. Ernest Carman, B. S., Ph. D., Professor of Geology, Ohio State University, Columbus, Ohio.

Sidney Longman Galpin, A. B., A. M., Ph. D., Assistant Professor of Geology and Mining, Iowa State College, Ames, Iowa.

Frank Cook Greene, A. B., M. A., Geologist, 30 North Yorktown street, Tulsa, Oklahoma.

Ferdinand Friis Hintze, A. B., M. A., Ph. D., Assistant Professor of Geology, Lehigh University, South Bethlehem, Pennsylvania.

George H. Hudson, Teacher of Biology, Physiography, and Nature Study Methods, Plattsburg Normal School. Supervisor of grade work and Nature Study. Plattsburg, New York.

Frederic H. Lahee, A. B., A. M., Ph. D., Assistant Professor of Geology, Massachusetts Institute of Technology, Cambridge, Massachusetts.

William Newton Logan, A. B., A. M., Ph. D., Associate Professor of Economic Geology, Indiana University, Bloomington, Indiana.

Robert Wilcox Sayles, A. B., Curator of Geological Museum, Harvard University, Cambridge, Massachusetts.

James Hough Stoller, A. B., A. M., Ph. D., Professor of Geology and Biology, Union College, Schenectady, New York.

William Arthur Tarr, B. S., Ph. D., Associate Professor of Geology, University of Missouri, Columbia, Missouri.

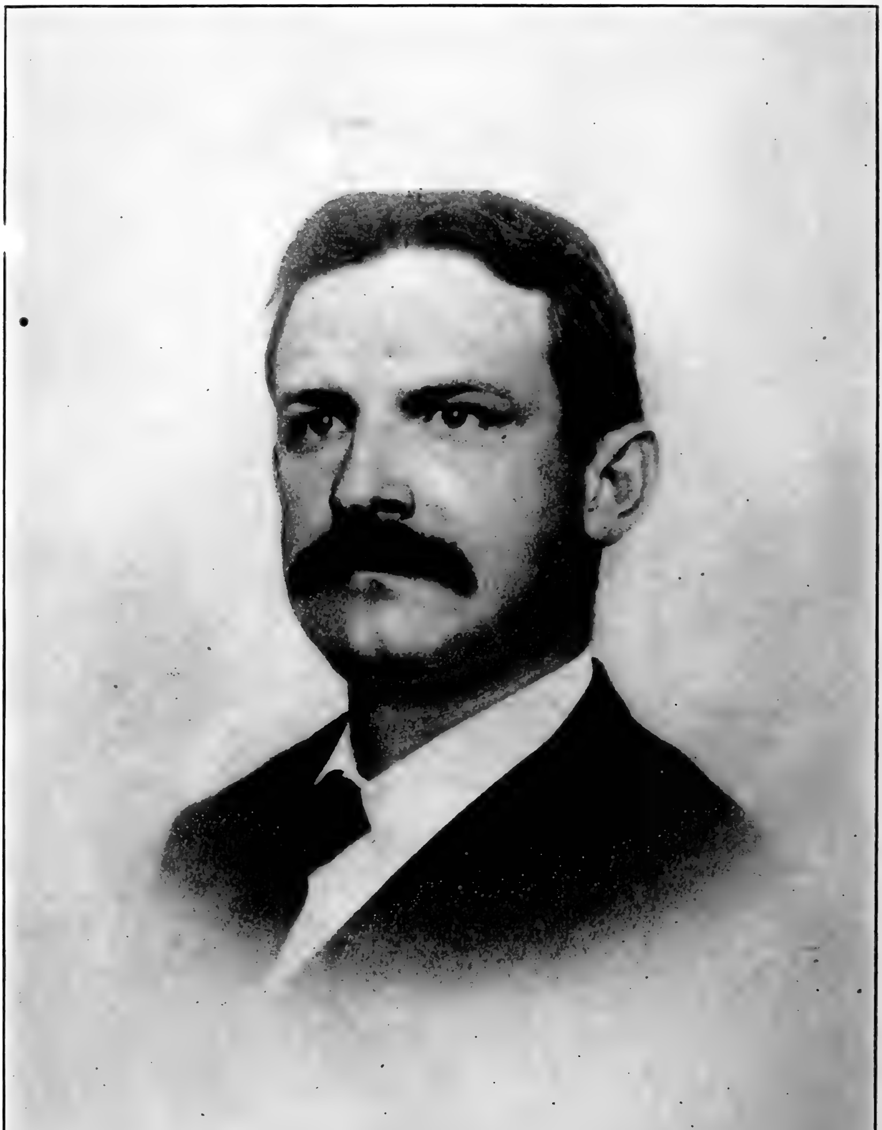
Charles Weldon Tomlinson, B. A., M. A., Ph. D., Associate in Geology, University of Illinois, Urbana, Illinois.

Francis Maurice Van Tuyl, A. B., M. S., Ph. D., Assistant Professor of Geology, Colorado School of Mines, Golden, Colorado.

NECROLOGY

Announcement was made by the Secretary that the Society had lost nine Fellows by death during the year 1917, namely, Robert Bell, Amos P. Brown, D. D. Cairnes, William Bullock Clark, Charles W. Drysdale, Arnold Hague, Robert H. Loughridge, A. H. Purdue, and H. M. Seely.

Memorials of deceased Fellows were presented as follows:



Very truly yours

Amos P. Brown

MEMORIAL OF AMOS P. BROWN [1]

BY R. A. F. PENROSE, JR.

Dr. Amos Peaslee Brown,[2] Professor of Geology and Mineralogy in the University of Pennsylvania, died on October 9, 1917, in his fifty-third year. He had not been in robust health for many years, and in spite of every effort of his physicians and his family his death was the sad culmination of his depleted condition.

Doctor Brown was descended from Henry Brown, who came to America from England in 1639 and settled in Massachusetts, where he was among the founders of the town of Salisbury. In the early part of the nineteenth century part of the descendants of Henry Brown went to Philadelphia and part to Maryland. Dr. Thomas Stewardson, of Philadelphia, a noted physician and botanist in the early part of the last century, was the brother of Doctor Brown's maternal grandmother.

Doctor Brown was the son of Amos P. Brown and Frances Brown and was born in Philadelphia on December 3, 1864. He was one of a family of seven brothers and two sisters, the rest of whom survive him. He received his early education at the Germantown Academy, under Dr. William Kershaw, and entered the University of Pennsylvania in 1882, where he received the degree of B. S. in 1886 and of M. E. in 1887. In 1893 he received from the University of Pennsylvania the degree of Ph. D.

Doctor Brown joined the Geological Survey of Pennsylvania, under Prof. J. P. Lesley, in 1887, and remained on it until 1889, during which period he did important scientific work. At first he was associated with Mr. Charles A. Ashburner in the western part of the State, but during most of his time on the Survey he was associated with Mr. Benjamin Smith Lyman. The results of Doctor Brown's work with Mr. Lyman are embodied in the publication of the latter, entitled "Report on the New Red of Bucks and Montgomery Counties," published in the Geological Survey of Pennsylvania, Final Report, Volume III, Part II, 1895. Doctor Brown's part of this work consisted especially of a study of the igneous rocks of the district.

In 1889 Doctor Brown was appointed Instructor of Mining and Metallurgy at the University of Pennsylvania, and in 1892 Professor of Geology and Mineralogy in the Auxiliary Department of Medicine at the

[1] Presented before the Society December 27, 1917.
Manuscript received by the Secretary of the Society January 8, 1918.

[2] The thanks of the writer for much information about Doctor Brown are due to his brother, Mr. Herbert Brown, and to Dr. Witmer Stone, Dr. E. T. Wherry, Dr. F. Ehrenfeld, Mr. Benjamin Smith Lyman, and others.

University. In 1895 he was appointed Assistant Professor of Geology and Mineralogy in the College of the University, and in 1903 full Professor of the same subjects—a position which he occupied until a few months before his death, when his failing health led him to resign.

After Doctor Brown left the Geological Survey of Pennsylvania he carried on scientific researches covering a wide field, including geology, mineralogy, paleontology, botany, and the subject of crystallography in relation to biology. Though his early education was that of a mining engineer and his first teaching position at the university was in mining and metallurgy, yet most of his research work was in pure science. In 1893 he went to the western part of the country with Prof. E. D. Cope to make paleontological studies in the Dakotas, Kansas, Texas, and Oklahoma, and somewhat later he made other trips West on similar work. In 1902 he visited Labrador, and in later years made trips to Panama, Jamaica, Antigua, and other places in the West Indies, where he made important geological and paleontological researches.

The best known of Doctor Brown's original work was "The Crystallography of Hemoglobins," published in connection with Prof. E. T. Reichert, of the University of Pennsylvania, by the Carnegie Institution of Washington in 1909. This remarkable work attracted wide attention at the time, both in America and abroad. From the standpoint of crystallography as well as of biology, it was an extremely valuable research and its thoroughness marked a distinct step in advance of anything that had previously been done on allied subjects.

At the time the United States Government was beginning the construction of the Panama Canal, Doctor Brown was one of the first to recognize the importance of a study of the geologic structure of the region. He visited Panama in 1910 and published several papers on the geology and paleontology of the country about the Gatun Dam. He also visited Jamaica, Antigua, and other places in the Caribbean Sea, where he made important studies of their geology and paleontology. Some of this work was done in connection with Prof. Henry A. Pilsbry, of the Academy of Natural Sciences of Philadelphia.

Doctor Brown had been a member of the Geological Society of America since 1905, and though his ill health prevented his attending many of the annual meetings, yet he always took much interest in its work. The last meeting he attended was that in Philadelphia in 1914, when he took a keen interest in trying to make it a success. For many years he was an active member of the American Philosophical Society and of the Academy of Natural Sciences of Philadelphia. He was one of the secretaries of the American Philosophical Society from 1908 to the time of

his death and was always earnest and faithful in the discharge of the duties of this office.

Doctor Brown's publications display a truly scientific spirit, and all who knew him realized that he had much more original material which he was reluctant to publish until his studies concerning it were more complete. Ill health often held him back in his work and the results he accomplished were attained in spite of physical ailments. The bibliography accompanying this memoir is probably nearly, if not entirely, complete; but Doctor Brown wrote for journals devoted to different branches of science, and the collection of the titles of his papers has been a matter of considerable difficulty. Moreover, Doctor Brown was a very modest and retiring man; he never tried to advertise his scientific efforts; he worked for the love of science and not for its notoriety, so that he left behind him peculiarly little classified information about himself.

Doctor Brown was held in the highest regard and esteem by all who knew him, for beneath his quiet and unassuming manner they recognized a man of remarkable learning, while his scientific grasp of the subjects in which he worked commanded the respect of all associated with him in similar investigations.

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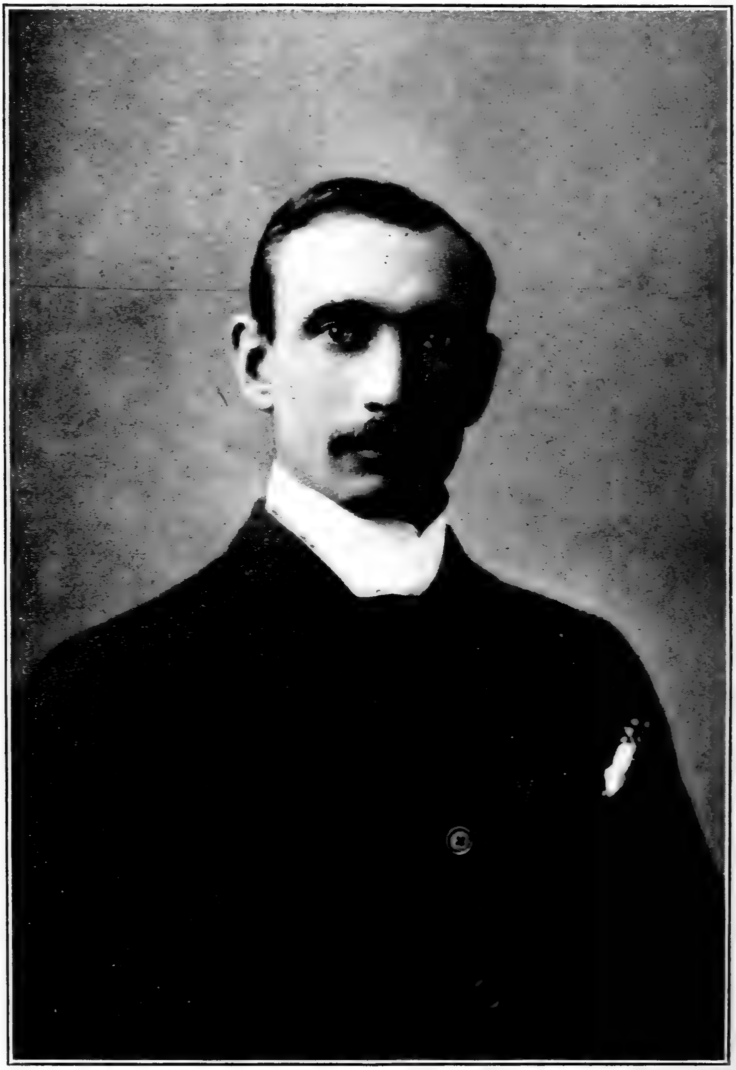

D. D. Cairnes

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MEMORIAL OF DELORME D. CAIRNES [1]

BY CHARLES CAMSELL

The death of Delorme Donaldson Cairnes at Ottawa on June 14, 1917, just as he was about to leave for his summer's field-work in the Yukon, removed from the field of geology one of the best trained and most industrious workers of the younger group of geologists in America. His place on the Canadian Geological Survey, to the staff of which he had been attached since May, 1905, will be difficult to fill because of his intimate knowledge of the geology and mineral deposits of Yukon Territory, where he spent in all eleven years of hard, uninterrupted work.

He was born in the village of Culloden, Oxford County, Ontario, on the 21st of August, 1879, and was thus in his thirty-eighth year when he died. Early in his life the family moved to Stratford, where his father was engaged in business. Here he obtained his early education, passing through the public school and the Collegiate Institute up to the point of university matriculation. In 1896 the family moved to the West, and eventually settled at Grand Forks, British Columbia, where for his

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[1] Read before the Society December 27, 1917.
Manuscript received by the Secretary of the Society December 13, 1917.

health's sake Cairnes took up outdoor work and for several years was engaged in prospecting.

Becoming interested in the study of geology through association with prospectors and mining men, he decided to pursue his studies further, and with that object entered the School of Mining at Kingston in 1901 to take the course in Mining Engineering. Of his work at the School of Mining, Prof. M. B. Baker writes:

> "In the meantime I had graduated and was lecturing in geology at this institution. I was therefore greatly surprised to see my old schoolmate in my classes, but I had no doubt of the results, for in Stratford he almost invariably led the classes. I was not surprised, however, to find that at the end of his first year in the School of Mining he had passed everything with flying colors and won the Chancellor's prize for the students obtaining the highest average on all the examinations of the first year. Cairnes kept up this record throughout his whole course, at the end of which he had actually maintained the standard of 80 per cent on all the work of the whole four years—a record that I do not believe has been equalled at this university. While taking his post-graduate course at Yale, the Dean of the Graduates School wrote me commenting on Cairnes' excellent preparation."

In May, 1905, Cairnes was appointed to the staff of the Canadian Geological Survey and did his first important piece of field-work that year in the foothills of the Rocky Mountains, west of Calgary. In the field season of 1906 he worked in the southern Yukon, and for the next ten years he spent every season in that territory.

After three years of field experience, his ambition to reach the highest rank in the geological profession compelled him to take up post-graduate work, and with this object he spent the winter of 1907-1908 in study at the Royal School of Mines, Freiberg, Saxony, and the succeeding winter at Heidelberg University, Germany. He completed his postgraduate work by obtaining the degree of Doctor of Philosophy in Geology from Yale University in 1910.

In October, 1907, he married Florence Mary, daughter of Dr. T. M. and Mary Fenwick, of Kingston, Ontario, who, however, predeceased him in November, 1914, after seven years of married life.

Besides being a Fellow of the Geological Society of America, Cairnes was a life member of the Freiberg Geologische Gesellschaft, a member of the American Association for the Advancement of Science, and of the Canadian Mining Institute, and to the publications of these societies he was a frequent contributor. His most important work, however, was done for the Canadian Geological Survey in Yukon Territory, where he spent the last eleven summers of his life in studying the geology and mineral

deposits of different parts of that region and in preparing a number of topographic maps. The results of his field-work in that region are embodied in a number of reports and memoirs, of which a list is given below. The list is an index of his industry, and it constitutes a very creditable record for a young man who was of necessity compelled to spend about half the time covered by the twelve years of the productive period of his life in field-work in the remote parts of Canada.

The outstanding features of Cairnes' character were his industry, his singleness of purpose, and his persistence in following up the object he had in view. To these qualities were due the measure of success which he attained and the rank he held in the geological world.

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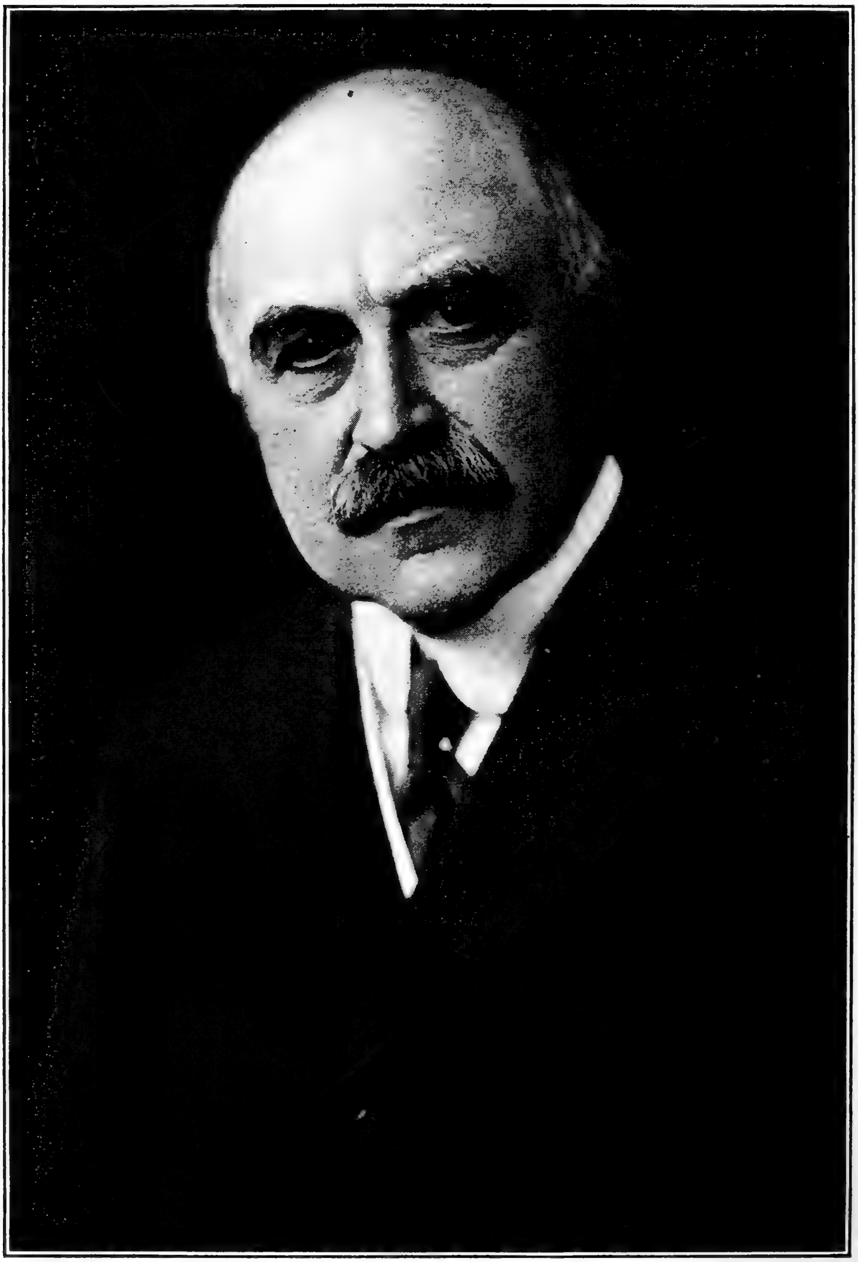

MEMORIAL OF WILLIAM BULLOCK CLARK [1]

BY JOHN M. CLARKE

It has been said of this distinguished member of our Society that he was the most useful citizen of his adopted State. The people of Baltimore and of Maryland have been called on by the public press "to pay high honor to the man who did so much for them."

As he moved about among us in these scientific meetings, engaging us with his spirited personality, his quick and cordial appreciation of others' achievements, his wise perceptions in the business of the Society, and his participation in our common interests in technical science, it may be that we thought he belonged to us alone, and that when he had given the passwords of our guild, spoken its vernacular, shared its spirit of research, and brought before us the sheaves of his harvest, his activities were here revealed and summarized. I think he would have had us believe that the purposes and principles which we embody were his highest concern; that the diffusion of a knowledge of geological science as a means of properly comprehending the material and spiritual relations of man to the earth and of man to his fellow was the important business of his full and vigorous life. Yet we may not have known that he turned from expositions before us of the anatomy of the Oligocene echinoids to his duties as a member of a civic commission engaged in improving the water front of the city of Baltimore; from exact determinations of coastal plain geology to the administration of child welfare problems in his adopted State. To us he was the geologist and the paleontologist. His other activities, if we knew of them at all, we were most likely to learn from others.

There must be some in this Society who looked on him as one of the older geologists. To one who was called on to prepare the memorial notice of Doctor Clark's predecessor at the Johns Hopkins, this hardly seems possible, and yet I suppose it may be true. We knew him here as the young Amherst graduate who had gone to the Hopkins to supplement the work of Prof. George H. Williams; as the promising geologist who succeeded the brilliant Williams in the professorship. We knew him as the man from outside, who had the rare courage and adeptness to organize and secure public support for a new and needed geological survey of the State of Maryland. Little by little we saw the results of this survey, carefully planned, leading cautiously through reports on

[1] Read before the Society December 27, 1917.
Manuscript received by the Secretary of the Society December 29, 1917.

practical problems and local developments, embodied in dignified dress, continuously and respectably issued, till its founder, conscious that his foundation and his grip were secure, a commanding general of geological forces, invaded the purer fields of the science and set his monuments in a series of splendid coherent volumes, one quickly following another, giving to his State an encyclopedia of its geology extraordinary in fullness, logical sequence, and beauty of execution.

So much we knew; and some of us who have served as State geologists and dare not take such achievements for granted as, permit me to say, too many teachers and the public are likely to do, we were consumed with admiration of his performances.

I have spoken of him as a commanding general of geological forces. The commanding general would never have been more than a lieutenant except as he could supplement his special knowledge with a quick, broad, and comprehending grasp of others' knowledge and apply it best to the general good. There lay his genius. He knew how to guide the treasure finders into the treasure house he was raising and how to build their jewels into a proper setting. He not only inspired men, but he discovered them; and no man whom he discovered or inspired, whom he set upon his feet and whose feet he turned into upward paths, lost his individuality. His organizations in the State Survey and in the university were not concerns in which the efforts of his coworkers were focused on their leader; he would not have it so, but rather on their work.

When his new house at Guilford was nearly finished, enough for occupancy, I happened to find open on the desk of his study, where the books were lying in careless piles, a copy of Grabau's Principles of Stratigraphy—a thoughtful volume and no reading for a summer's afternoon. In all the confusion of an unsettled home and amidst his duties as university counselor, university professor, member of committees and commissions, scientific and civic, he was reading this book consecutively, just before going to bed each night, and he had nearly finished it. Undoubtedly he did finish it in these studious ends of busy days, and it was by such practices as this that his active mind kept abreast of the advances of his own science. Thus always with a good general. The hours when he is closeted with himself and his most intimate concerns are the wellspring of his competency. Those who knew Doctor Clark closely can tell of the quality of his friendship. Unsparing in his commendation where he saw it deserved, he did not let commendation go unsupported. How often and persistently he put aside his own claims in favor of those associated with him; labored for them, forgetful of himself; how gladly he took his friends to his heart and shared with them his purposes, sought their

counsel, and prided himself on their companionship—these things are known only to them. They are the qualities which in this assembly have been somewhat veiled.

He was a lover of men and he was wise in his use of them. He sought them, especially men who were doing things or men who could help him do the many things he was called on to do. Thus the circle of his influential acquaintance was very large, and he knew which way to turn when any new demands were put on him.

There must come many times to every one of us now when we feel the State needs the service we are competent to render, but it is not given to many men to create the opportunity for such service; and it is one thing to construct a beneficial public agency which will run as long as its creator stands on the bridge, but quite another to organize so securely that it will continue to run when the captain has left the ship and another has taken his place. The State of Maryland's Weather Service, its fine system of public highways, its Forestry Service, its Boundary Survey—these are the permanent witnesses of his service to her. Baltimore's streets, parks, docks, and sewers, her prospective civic center, her federated charities, her aid for dependent children, her war against tuberculosis—these, too, are witnesses of his ability and will to serve.

Another place must be reserved for the measure of his university usefulness. I have heard his students say that the Geological Laboratory at his university was the ideal place for a student, filled with an atmosphere of lofty motives and the inspiring joy of work; and there are not a few graduates of his department who have said that he was the most potent influence in their lives.

The students who gathered around him caught his ideals—there was to be no specializing among them till they had covered the entire broad field of the science, organic and inorganic, and were then in some more adequate measure inoculated with his vision. That this paleontologist graduated from his department geologists, paleontologists, paleobotanists, geophysicists, highway engineers, and meteorologists was a natural realization of his proper university business; but a more vivid expression of his earnest conviction that geology is an essential science is that he had convinced the engineering faculty of the imperative need of the full undergraduate course in geology for candidates in civil engineering.

Doctor Clark's last work was for his country. He had entered on and perfected the organization of an extensive survey of the Atlantic Seaboard and Gulf States for the purpose of locating all available materials for road construction and fortification, and to make these important data of location and transportation immediately available. Into this under-

taking he put his intense energy, made quick connections with many men and cooperating agencies, traveled far, made sharp appointments with his associates at hotels and railroad stations, grasped and covered the entire field, designated his lieutenants and formulated his suggestions—and then he died, in the heart of a fine service.

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MEMORIAL OF CHARLES WALES DRYSDALE [1]

BY J. AUSTEN BANCROFT

It was with widespread regret that the news was received from British Columbia that, on July 10, Dr. Charles Wales Drysdale, one of the most vigorous, efficient, and universally popular of the members of the staff of the Geological Survey of Canada, together with his field assistant, Mr. William John Gray, of Vancouver, who was a student in the University of British Columbia, had been drowned in the upper reaches of the Kootenay River. Accompanied at the time by Mr. L. D. Burling, one of

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the paleontologists of the Geological Survey of Canada, Drysdale and his party approached the Kootenay River from the eastward and near the point at which it is joined by Cross River. Throughout this portion of its course the Kootenay River flows swiftly and is about 225 feet wide. Having spent the preceding day in a vain search for a possible fording place, it was decided to swim the horses and build a raft to transport the outfit across the river. The place selected for crossing the river lies about three miles above Cross River, where, near its eastern bank, a small island is situated that could be reached by fording. Opposite to this island and for about 400 yards along the western bank of the river, landings could readily be made, but just below this, at a curve in the river, the bank rises as a steep cliff, against and beneath which the water swirls with much force.

A staunch raft, 16 feet by 8 feet, was constructed of logs selected from a log jam on the northern side of the island. With the impetus of a strong shove from some of the party on the island, the raft with its first load was paddled across by Doctor Drysdale and his packer, Mr. George M. Smith, and a landing was made about 300 yards above the cliff. Mr. Burling then crossed on one of the horses and assisted in towing the raft upstream, so that on the return passage it would readily make the island. As "chief" of the party, Doctor Drysdale insisted on accompanying Smith in taking the raft back to the island for the remainder of the outfit. Having reached the island, the raft was again loaded. The horses then swam safely across with Emmons, the cook of the party, on the one that was leading. Finally, the loaded raft, leaving the island without an initial shove, but propelled in this instance by three paddles plied by Doctor Drysdale and Messrs. Gray and Smith, was rapidly carried downstream, struck the cliff already referred to, and capsized. Doctor Drysdale and Mr. Gray jumped toward an embayment in the bank and were immediately carried down by the heavy undertow; Smith was able to climb on the overturned raft and thus saved himself.

By the death of Charles W. Drysdale, the Geological Society of America loses a young and recently appointed member, who through untiring and enthusiastic effort had contributed much to our knowledge of the complex geology of several of the most important mining camps of British Columbia. His was a short but exceptionally brilliant career.

Born in Montreal on November 1, 1885, he was the younger son of William and Mary (Wales) Drysdale. His father is a highly respected citizen of Montreal, who now occupies the position of Government Appraiser for books and stationery in the Canadian Department of Customs at Montreal.

In June, 1903, after completing his preparatory course in a private school and in the Montreal High School, Drysdale determined to see something of the world before entering college, and to this end secured a return passage to South Africa as steward to the engineers on a steamer sailing from Montreal. On this trip he displayed those qualities of kindly independence and keen observation that characterized his collegiate career and later work.

On entering McGill University in 1904, he spent one year in the Faculty of Arts, but in the following summer, while engaged in mining development work at Mammoth, Montana, he decided to change his course of study to the Faculty of Applied Science, and, in 1909, he graduated in Mining Engineering. He was a thorough, painstaking student, possessing an orderly mind which, by readily sorting out facts according to their relative importance, arrived at sound conclusions. His genial disposition, his quiet, unassuming manner, and the absolute sincerity of all his activities made him a universal favorite among his fellow-students. He was a member of the Phi Delta Theta fraternity.

His summer holidays were devoted to acquiring a variety of experiences that later stood him in good stead. During the summer of 1906, he was a draftsman on the staff of the Dominion Coal Company, at Sydney, Nova Scotia; in 1907, he was prospecting for mineral deposits in the Gowganda district of northern Ontario. During the college session of 1907-1908, he first made his acquaintance with geology, and in the following summer gained his first experience in field-work on the Geological Survey of Canada, being sent to the boundary district in British Columbia as an assistant to that sterling character and inspiring geologist, Capt. O. E. Le Roy, of the 46th Battalion of the Canadian expeditionary forces, who in the latter part of last October died of wounds received while leading his men in Flanders. Drysdale returned to his senior year at McGill University filled with enthusiasm for geology and with a quiet determination to thoroughly prepare himself for work on the many problems of economic geology in British Columbia.

During the next three years (1909-1912), winters in the Graduate School of Yale University alternated with summers spent in field-work in British Columbia. At Yale, because of the commendable character of his work, he was awarded a fellowship, was elected to Sigma Xi, and in 1912 received the degree of Ph. D. The thesis that he submitted for this degree was entitled "Geology of Franklin Mining Camp, British Columbia," and it was later published as Memoir 56 of the Canadian Geological Survey.

For two years after completing his studies at Yale University, he was

Assistant Geologist on the Geological Survey of Canada and, in 1914, was appointed to the senior rank of a regular field officer. All of his geological work was done in his chosen field of British Columbia.

Drysdale's intense devotion to the geology of this field is reflected in the character and importance of the reports that he produced in a comparatively short time. In his three memoirs on the Franklin, Rossland, and Ymir camps, respectively, clear and graphic descriptions of the complex succession of events that produced the existing geological relations within these areas are illustrated by cleverly executed diagrams, sketches, and sections. Of especial interest also are his detailed descriptions of the petrographical character and relative ages of the igneous rocks in these highly disturbed areas.

But it is chiefly in connection with his application of geology to the solution of problems relating to the ore deposits of these mining districts that Drysdale made his reputation. Since its discovery in 1890 to the close of 1916, the Rossland Mining Camp has produced 5,282,242 tons of ore, with gold, copper, and silver contents worth $69,678,670—a production which exceeds in value that of any other lode mining camp in British Columbia. It is merely because of the exceptional economic importance of the area involved that Drysdale's memoir on Rossland has attracted more attention than his memoirs dealing with the Franklin and Ymir Mining camps.

In 1894 and 1896, a reconnaissance geological survey of the Rossland district was made by Mr. R. G. McConnell, who is now the Deputy Minister of Mines in Canada. In 1905 and 1906, this area was studied in more detail by Mr. R. W. Brock and Dr. G. A. Young and, in 1906, a brief preliminary report by Mr. Brock was published. In November, 1907, Mr. Brock assumed the duties of Director of the Geological Survey of Canada, and although a detailed geological map of Rossland appeared in 1909, he was unable to find time to prepare his final report. The geological work in this area was not completed until, in 1913 and 1914, Drysdale made a very thorough and detailed study both of the surface and underground in the mines and, making free use of the data collected by Brock and Young, produced one of the most valuable of the memoirs that have been published by the Geological Survey of Canada.

During and since the Carboniferous period, the Rossland district has repeatedly been invaded by ascending magmas which at times were associated with the development of volcanic activity. The results of his observations as to sequence of igneous intrusions, detailed petrographical distinctions between the various rock types and phases of the same type, the development of fault and fissure systems of different ages, and as to

the mineralogical character, mode of occurrence, and genesis of the different types of ore deposits, Drysdale applied to the directing of development work in search for ore and with very successful results. He showed that there were at least two periods of mineralization: in the first and main period, following the intrusion of the Trail batholith of granodiorite and monzonite during Jurassic time, there were magmatic emanations containing copper, sulphur, nickel, iron, gold, lead, silver, cobalt, antimony, and molybdenum; in the second period, following the intrusion of the Coryell batholith of pulaskite of Miocene age, there were alkaline solutions containing gold During the first period, bodies of sulphide ores were developed by processes of replacement along fissure and shear zones formed chiefly in the cover rocks of the Trail batholith and along formational contacts, while the mineralization of the second period was of the character of secondary enrichment.

That Drysdale's work was appreciated by the mining men of Rossland was shown at a meeting of the Western Branch of the Canadian Mining Institute on October 26, 1916, in Trail, British Columbia, when the following resolution was submitted by Mr. M. E. Purcell, the superintendent of the Consolidated Mining and Smelting Company's Center Star-War Eagle group of mines:

"*Resolved*, That we express our hearty appreciation of Dr. Charles Wales Drysdale's valuable contribution to economic geology in the work entitled 'The Geology and Ore Deposits of Rossland, British Columbia.' "

In supporting the resolution, Mr. S. G. Blaylock, assistant manager of the Consolidated Mining and Smelting Company, said:

"The work which Doctor Drysdale has accomplished in this section can only be appreciated thoroughly by those who know the Rossland camp. He has solved numerous problems and pointed out a great many things that were not before known to any of us. His work was all the more valuable in that as it progressed he instructed various men interested in the district in the different rock formations and ore-bearing measures, so that we did not have to wait a long period of time until his completed report could be issued before we could take advantage of the knowledge he gained at Rossland. I may say that his findings have been of real value in laying out development work in the mines of the camp. I am sure we all give Doctor Drysdale every credit and wish him the great success he deserves."

It is pleasing to think that Drysdale lived to receive the above sincere tribute to the merit of his work. Moreover, the Consolidated Mining and Smelting Company offered him a position on their staff at a salary very much larger than he was receiving, but to him, money was no measure of results achieved, and, in addition, feeling that during the war his country

needed his services in the broader field of helping to stimulate the production in British Columbia of all minerals required for munitions and other war purposes, he declined the offer.

In December, 1916, he was elected a Fellow of the Geological Society of America. He was also a member of the Canadian Mining Institute and of the Canadian Club at Ottawa.

In May, 1912, he married Plessah Beryl Ogilvie, eldest daughter of P. E. Ogilvie, ex-Mayor of Glace Bay, Cape Breton, Nova Scotia, and to this union two daughters and a son were born.

Shortly after Doctor Drysdale's death, an article written by Mr. E. Jacobs, secretary of the Western Branch of the Canadian Mining Institute, appeared in a newspaper in Victoria, British Columbia, which brings a review of his work to a conclusion in the following appropriate sentences:

"Of all the men who in recent years have done field-work in British Columbia in connection with economic geology, the opinion may be expressed that he was distinctly in the lead. Highly efficient, untiring, assiduous in his investigation, and diligent in preparing for publication the results of his work, he set an example that it would be to public advantage to have emulated by others. Added to these high qualifications for his important work were kindliness and courtesy that freely and generously responded to inquiry concerning problems and difficulties met with in mining, so that all who came in contact with him in the field or underground appreciated his pleasing personality."

Doctor Drysdale has thus left a splendid record of much valuable work well done. In addition to his scientific attainments, he possessed those qualities of heart and mind which made him beloved by those who were fortunate enough to know him. His spirit should live long as a stimulus to the maintenance of high ideals in geological work in Canada.

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Very truly yours
Arnold Hague.

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In addition to the above, Doctor Drysdale had very nearly completed a memoir on the Bridge River Mining area, British Columbia, and had partially prepared a report on the Slocan Mining area, British Columbia. These manuscripts are being edited and will be published by the Geological Survey of Canada.

MEMORIAL OF ARNOLD HAGUE [1]

BY JOSEPH P. IDDINGS

Arnold Hague was born in Boston, Massachusetts, on December 3, 1840. His father, Rev. Dr. William Hague, was a Baptist minister, as was also his great-great-grandfather, William Hague, who was active in his pulpit at the age of eighty-five, in his home in Scarborough, England. William Hague, the father of Arnold, was born near Pelham Manor, New Rochelle, New York, being a descendant, on the maternal side, of a Huguenot family which left France for Martinique, and later moved to New York State, and settled in the place afterward called New Rochelle. He was also descended from David Nimham, a North American Indian, who acted as guide for Washington's troops through the forests of Westchester, New York. Arnold Hague's mother was Mary Bowditch Moriarty, of Salem, Massachusetts, a granddaughter of Deborah Bowditch

[1] Read before the Society December 27, 1917.
Manuscript received by the Secretary of the Society January 14, 1918.

and a relative of Nathaniel Bowditch, the mathematician. The family lived in Salem for three or four generations.

When Arnold was twelve years of age the family moved to Albany, where his father was pastor of the North Pearl Street Baptist Church. In Albany Arnold attended the Albany Boys' Academy, from which he graduated in 1854. He often attended the meetings of the State legislature after school hours, and with a number of boy friends indulged in a senate of their own, where they debated questions of interest to themselves. In 1856 his father took the family to New York City, where he was pastor of the Madison Avenue Baptist Church.

In the autumn of 1861, when the Civil War was in its early stages, Arnold, at the age of twenty, having been unable to enlist in the army for physical reasons, entered the Sheffield Scientific School of Yale College with advanced standing, taking up the studies of Junior year in what was known as the Chemical Course, there being at that time only two others—the Engineering and the General. Chemistry was taught by John Porter and Samuel W. Johnson, with O. D. Allen and Peter Collier as assistants. Metallurgy and mineralogy were taught by George J. Brush; geology by James D. Dana, and modern languages by William D. Whitney. Theodore Woolsey was the President of Yale. As the attendance in college was affected by the war, Hague's class, which graduated in 1863, contained only four students; so that each student undoubtedly received very direct personal attention from his instructor, and one may imagine the inspiration which the student, Hague, must have received from such men as Dana, Brush, and Johnson.

When Arnold Hague entered the Scientific School, Clarence King was in the Senior class and O. C. Marsh was a graduate student, having graduated from the Academic Department in 1860 with the degree of A. B. Other students with whom Hague was associated, who were in the graduate school at that time, were J. Willard Gibbs and Ellsworth Daggett, who afterward became a mining engineer. The acquaintances which began in this way with King and Marsh were destined to play a great rôle in the future life of Arnold Hague, especially the friendship with Clarence King; for while we have no record of Hague's experiences and aspirations during his college life, it is evident from subsequent events that the friendship for these two men influenced very much of his life's work.

After graduation in 1863 with the degree of Ph. B. he went to Germany, spending a year in Göttingen, improving his knowledge of the language, and the next year in Heidelberg in Bunsen's laboratory, where most of his time was devoted to chemistry and mineralogy. It is to be

noted that in 1851 Bunsen had suggested the hypothesis of a pyroxenic magma and a feldspathic magma as the sources of all intermediate volcanic rocks, which might be formed by their mixture—an idea he had gotten from studying the basaltic and rhyolitic lavas of Iceland. It is probable that Hague became acquainted with this theory directly from Bunsen, which may account for the hold it had on him in later years, though he never advocated it directly. From Heidelberg he went to the Bergakademie in Freiberg, Saxony, in the spring of 1865, where he met for the first time S. F. Emmons, who had been there the previous year. This was the beginning of another friendship which was to continue throughout life and was to influence the careers of both these embryo-geologists, who were within four months of the same age. Emmons, having had a year's experience at the Bergakademie, became the adviser of Hague as to his best course and joined him in all the week-end excursions with von Cotta, visiting many parts of Saxony and studying petrology according to von Cotta's text-book. Their evenings were often spent studying the geological map of Saxony, and thus acquiring their initial experience in geological cartography. In a reference to this experience Hague has said: "Both came to realize the influence of Cotta on our future careers, as he gave us much of his time." [2]

Bernhard von Cotta was the author of a text-book of petrography, "Die Gesteinslehre," the second edition of which was published in 1862, and this book became Hague's guide and basis of petrography. In it all rocks were classified according to mode of origin: as eruptive, metamorphic, or sedimentary; and eruptive rocks were divided into two groups on a chemical basis: 1, those poor in silica, or basic; 2, those highly siliceous, or acid. Each group was further divided into volcanic and plutonic. The separation into basic and acid appears to have been made with Bunsen's hypothesis in mind, but not directly as an expression of it, for von Cotta, in 1858, had proposed the hypothesis that the solid crust of the earth consisted of highly siliceous substances, and that the fluid portion beneath had about the composition of the most basic rocks, and that the variations in composition of eruptive rocks were due to the variable amounts of the solid siliceous crust which was taken up by the basic magma during its passage toward the surface of the earth.

Although Sorby had made the first use of the microscope in studying rock sections in 1851, and Zirkel had published microscopical descriptions of rocks in 1863 and 1864, the application of the microscope to petrography had not attracted any attention when Hague was preparing

[2] Arnold Hague: Biographical memoir of Samuel Franklin Emmons. National Academy of Sciences, vol. ii, 1913, p. 315.

himself for his geological career. In fact, it was not until seven years after his return to this country that microscopical petrography began to attract general attention.

In December, 1866, Hague returned to his home, which was now in Boston, Massachusetts. He was just twenty-six years old and had had a liberal education in chemistry, mineralogy, petrography, and geology, as they were taught in those days. A few weeks after his return he met Clarence King in New York and had a chance to learn from him his plans for a geological survey across the western cordilleras along the line of the proposed transcontinental railroad. One who knew King in later life can imagine the enthusiasm with which at the age of twenty-five he must have developed the prospectus of the enterprise and the romance with which he must have enveloped it. He offered Hague a position as assistant geologist if the proposed plan of the survey should be authorized by Congress. It was naturally accepted on the spot, and Hague returned to Boston to find his friend Emmons and acquaint him with his good luck. Shortly afterward he introduced Emmons to King, and this led to the engagement of Emmons as another assistant, and was the commencement of that geological triumvirate which accomplished so much for American geology through what was known as the Geological Exploration of the Fortieth Parallel.

On May 1, 1867, Hague and Emmons, with several other members of the scientific party, sailed from New York for San Francisco by way of Panama—a three weeks' trip, but much less difficult than the journey across the continent at that time, before the railroad was completed, when through travel was by Wells, Fargo and Company's stage-coach. After a few days in San Francisco the first camp was established in the outskirts of Sacramento, where final equipment for the field-work of the survey was completed. The field force consisted of geologists, topographers, an ornithologist, a botanist, and a skilled photographer, besides packers and cooks, for field-work was conducted by three parties—one under Hague, another under Emmons, exploring separate areas, while the third party was under King, who kept in touch with the work of the two assistants, besides undertaking special researches himself. Since geological and topographical work was carried on simultaneously in the same district, the geologist did not have the map on which to plot his results until a year after the field-work of a particular district had been done. Moreover, the scale of the maps was four miles to the inch and the character of the geological work was reconnaissance.

The country to be explored was a wilderness, inhabited sparsely by Indians, and to a large extent desert. It was thought advisable by the

War Department to provide the expedition with a cavalry escort of 25 men, and occasionally a soldier accompanied the geologist into the mountains. The area to be surveyed was a belt of country 100 miles wide, extending from the California State line eastward to the Great Plains of Wyoming and Colorado, east of the Rocky Mountains, embracing the line of the first transcontinental railroad. The work of the survey began at the western edge of the great sagebrush desert, in the region of Pyramid and Winnemucca lakes, and extended through parts of Nevada, Idaho, and Utah, across the Rocky Mountains, although in the published report the region is described from east westward.

The season of 1867 was spent in the Humboldt country, in western Nevada; that of 1868 was occupied with the remainder of the Great Basin as far as the western edge of the Salt Lake desert. The third field season, in 1869, was devoted to the mountains and valleys of the Salt Lake region and the Wasatch Mountains to the east of it. During the three following seasons the exploration covered the Mesozoic and Tertiary areas of Utah and Wyoming, the Laramie plains, the northern extension of the Front Range, and the eastern slopes of the mountains. In addition to the survey of the area of the Fortieth Parallel, Hague explored Mount Hood, while King investigated Mount Shasta, and Emmons, Mount Rainier, each studying the glacial phenomena and collecting volcanic rocks.

The winter of 1867-1868 was spent in Virginia City, Nevada, studying the Comstock Lode and the geology of the adjacent country situated just south of the belt of the Fortieth Parallel Survey. In Volume III of the published reports, entitled "Mining Industry," Hague contributed a chapter on the "Chemistry of the Washoe Process," which included a description of the mineralogical character of the ore, the chemical action of mercury and other reagents, and pan experiments. The latter were conducted at the Sheffield Laboratory of Yale College, with the assistance of Mr. Ellsworth Daggett. Hague also wrote a chapter on the geology of the White Pine district. Successive winters were spent in San Francisco, Washington, and New Haven. After the completion of field-work, in 1872, the offices of the Survey were located in New York City, where the report and accompanying atlases were prepared. The collection of rock specimens was deposited with the American Museum of Natural History for safekeeping.

In 1874 Emmons was sent to Europe to study the methods of European geological surveys and to obtain the best and latest geological literature. He was also instructed to confer with Professor Zirkel, who had just published his book on microscopical petrography, in 1873, and "to

induce him, if possible, to visit America and study in the presence of the collectors their collection of rock specimens, for at that time no American geologist had any practical knowledge of this new branch of geology. From this visit resulted Zirkel's volume on microscopical petrography, which marked the opening of a new era in geological study in the United States." [3]

It is interesting to note the phases of petrography through which the work of the Geological Exploration of the Fortieth Parallel passed, since this was the first of the larger surveys in this country that took a deep interest in the petrography of eruptive rocks. It began with King's interest in the lavas of the Pacific Coast volcanoes and the igneous rocks of the Sierra Nevada. This took definite form through his association with Baron von Richthofen during his visit to the Pacific coast, where he studied the Tertiary volcanic lavas and, observing their strong resemblance to those of Austro-Hungary, wrote his paper on a National System of Volcanic Rocks, published in San Francisco in 1868. This gave King, no doubt, his definite conceptions of rock varieties and their order of eruption, which represented the most advanced views of pre-microscopic petrography and placed King in advance of his assistants of von Cotta's school. Under these influences the volcanic rocks of the region surveyed were studied and classified. After the collection had been made and brought to New York, Zirkel, the young creator of microscopical petrography, was invited to study the specimens in the presence of the collectors, and we have been told he was much influenced by the eloquent and forceful exposition of King and his associates regarding the nature and occurrence of the rocks. We are led to believe that Zirkel's judgment was warped to some extent in determining the composition of some of the specimens, in particular what were at that time called propylites and trachytes. This opinion would seem to be justified by Zirkel's own statement in his letter transmitting the report to Clarence King. The report, written by Zirkel in English, was edited by King and published as Volume VI, in 1876. On its receipt by the geologists of the Survey, appropriate notes regarding the microscopical characters of particular rocks were inserted in the reports of Hague and Emmons in Volume II, which was printed the following year. In this manner were blended the best of pre-microscopic petrography with the earliest products of microscopical research.

The results of Hague's geological work in connection with the exploration of the Fortieth Parallel are published, with those of Emmons, in Volume II, "Descriptive Geology," each describing those parts of the

[3] S. F. Emmons: Clarence King. Am. Jour. Sci., 4th ser., vol. 13, 1902, p. 229.

region specially studied by himself, in some instances with the aid of the others field notes or those of Clarence King. Hague's comment on it may be quoted from his memoir of Emmons, prepared for the National Academy of Sciences (page 321):

> "It is a description of the country, treated geographically, beginning on the Great Plains and progressing westward across the widest part of the northern cordillera. An endeavor is made to give the structural details and salient geological features lying between the meridian 104 degrees west and the meridian 120 degrees west, the latter being the eastern boundary of the State of California. The volume of atlas maps upon which the early geology was laid down, including the accompanying cross-sections, bears the imprint of 1876. . . . Nearly all the great divisions of geological time are represented on the atlas sheets, and in Volume II are described with more or less detail. In this volume the term Laramie formation is used in geological literature for the first time. The necessity for a formation name for a great series of beds covering many hundred square miles in area was readily recognized. The name was suggested by one of the authors of the volume and warmly indorsed by Mr. King, provided it would be acceptable to Doctor Hayden, who had, of course, observed the formation at a number of localities in the Rocky Mountains. Doctor Hayden cordially agreed to the adoption of the term Laramie. During the last thirty years probably no geological horizon has been more discussed from many points of view, with all the accumulated evidence brought to bear upon the study of this series of beds."

Mr. Hague is the geologist who first suggested the use of the term Laramie formation.

In 1877 Hague became government geologist of Guatemala, where he spent a year studying its mines and volcanic districts. In 1878 he went to China, at the instance of Li Hung Chang, to study the gold, silver, and lead mines of north China for the Chinese government. Owing to conflict of authorities and excessive conservatism on the part of some of the higher officials, he was not permitted to accomplish much of economic value, but enjoyed unusual opportunities for visiting remote parts of the country under government escort. He left no record of his experiences or observations during these years of service.

In the spring of 1879 the United States Geological Survey was established by act of Congress and Clarence King was appointed its Director. The first field parties were organized and began work the ensuing summer, and Mr. Hague was appointed a geologist, to enter on his duties on his return from China. He came back by way of London in March, 1880, and it was in London that the writer of this memoir met him by appointment on his way home from Heidelberg, where he had been studying with Rosenbusch, King having promised him a position as assistant to Hague when Hague should take up his duties on the Geological Survey. The

meeting took place most informally in Hague's lodgings, while he was finishing his morning toilet, and was followed by visits to the Museum of Practical Geology in Jermyn street, where the offices of Sir Archibald Geikie, Frank Rutley, and other members of the Geological Survey of the United Kingdom were located. The few days together in London and the voyage home to New York were the beginning of years of intimate association in office and camp life, to which the writer looks back with the happiest recollections.

On reaching New York, Hague proceeded to Washington to report in person to King and to take the oath of office, which he did on April 10. The first duties of Hague and his assistant were to arrange and catalogue the extensive collection of rock specimens made by the exploration of the Fortieth Parallel, which had been deposited in cabinets in the American Museum of Natural History, but had become displaced with respect to their labels by the movement of the drawers containing them. This necessitated the identification of the specimens megascopically by comparison with the descriptions in Volume II and microscopically by a study of the rock sections described by Zirkel—a study of great value to the young assistant. The work occupied a large part of the following three years, which, however, were devoted to a number of other duties.

The summer and autumn of 1880 were spent by Mr. Hague in the field study of the Eureka district, Nevada. His assistants were Charles D. Walcott, fresh from the Grand Canyon of the Colorado, and J. P. Iddings, still fresher, from laboratory and lecture rooms. The district, 20 miles square, embraced Paleozoic strata and volcanic lavas, with silver-lead mines and prospects in the desert region of central Nevada. Almost the first night in camp came near being the last, for Mr. Hague in trying to drive from his sleeping-tent a foraging mule was kicked in the head above the temple and severely cut, barely escaping with his life. Fortunately he recovered rapidly and the field-work proceeded normally.

It had been the intention of the Director that Hague should establish a branch office of the Geological Survey in San Francisco, and should undertake a detailed study of the Pacific Coast volcanoes, beginning with Lassen Peak. In fact, Hague had been appointed geologist in charge of the Division of the Pacific. But a sudden change in King's plans, resulting in his resignation of the Directorship of the Survey in March of the following year, 1881, caused Hague to relinquish the position and return with his assistants to New York, where they found office room in the American Museum of Natural History. Work on the Fortieth Parallel collection was continued, in addition to the preparation of the report on the geology of the Eureka district.

No field-work was undertaken by Hague and his assistant, Iddings, during the two following years, 1881, 1882, but a microscopical study of the volcanic rocks collected by King, Hague, and Emmons from the Pacific Coast volcanoes, and a further study of the igneous rocks of the Great Basin of Utah and Nevada, in the collection of the Fortieth Parallel, were made by Iddings, and joint papers on the results were published by Hague and his assistant. In like manner a microscopical study of the collection of rocks used by Dr. George F. Becker in preparing his monograph on the Comstock Lode was made, and a joint paper based on the results was published by Hague and Iddings as Bulletin 17 of the United States Geological Survey. A joint paper was also prepared on volcanic rocks from Salvador, Central America, which had been collected by W. A. Goodyear, a classmate of Hague at Yale.

In 1883 Hague was appointed geologist in charge of the Survey of the Yellowstone National Park and vicinity, and began field-work in August of that year with a large party of assistants, including three assistant geologists—W. H. Weed, G. M. Wright, and J. P. Iddings; a physicist, William Hallock; a chemist, F. A. Gooch; a professional photographer, W. H. Jackson, and a disbursing clerk, C. D. Davis. The completion of the Northern Pacific Railroad later in the summer attracted general attention to the region and added to the interest taken in the natural phenomena for which the park has become famous; for besides the geological features, which were the object of the survey, the park was to be converted into a national pleasure resort for those interested in geysers, hot springs, and natural scenery of a remarkable character. It was to be placed under guard, as a huge game preserve, and was subsequently set aside as a forest reserve and a protected reservoir for the headwaters of the two great rivers—the Yellowstone-Missouri and the Snake, or Shoshone. In the prosecution and advancement of these various phases of development of the Yellowstone National Park, Hague took an active and prominent part, urging their importance on the government authorities in Washington and advising as to the proper administration of the laws and regulations whereby the various features of the park could best be preserved and its functions as pleasure resort, game and forest reserve could best be maintained. He was an ardent advocate of the preservation of the striking features of the region in their natural state and for placing hotels and other buildings where they would not mar the attractiveness of the localities to which they were tributary. He was a vigorous opponent of the attempt to introduce a railroad in the national park.

In the survey of the region he was especially interested in the study of the geysers and hot springs. He maintained a general oversight of the

detailed investigations of his assistants into the geological structure of the region, which is mostly covered by igneous rocks, with smaller areas of stratified rocks exposed in several mountain ranges, and he investigated portions of the area in detail himself. The region surveyed was over 3,000 square miles in extent and the field-work continued for seven seasons, from 1883 to 1889. The following season Weed and Iddings, under the charge of Mr. Hague, explored and mapped the geology of the area north of the Yellowstone National Park, which is known as the Livingston quadrangle.

The descriptive geology, petrography, paleontology, and paleobotany of the park have been published as part 2 of the Yellowstone Park monograph, in which certain chapters have been prepared by Hague. He has also made reports on the work from time to time in the Annual Reports of the Director of the United States Geological Survey, besides writing several special papers which appeared as presidential addresses before the Geological Society of America and the Geological Society of Washington—one on the "Early Tertiary volcanoes of the Absaroka Range"; the other on "The origin of the thermal waters in the Yellowstone National Park." In 1893, with T. A. Jaggar, Jr., as assistant, he studied the geology of the country east of the park, which had been set aside as a forest reserve and annexed to the Yellowstone Park reserve. He visited the Yellowstone Park a number of times to continue his observations of the hot springs and geysers. A list of his scientific publications is given at the end of this memoir.

In 1885 Arnold Hague was elected a member of the National Academy of Sciences, and served as its Home Secretary from 1901 to 1913, and represented the Academy at various celebrations and anniversaries of foreign universities and learned societies. He was appointed a member of the Forestry Commission in 1896 and took an active part in its work. He was a Fellow of the Geological Society of London and of the Geological Society of America, being elected its President in 1910. He was a member of the American Philosophical Society, a Fellow of the American Association for the Advancement of Science, of the Society of Naturalists, the Institute of Mining Engineers, the Washington Academy of Science, and the Geological Society of Washington. He was a vice-president of the International Geological Congress at Paris in 1900; at Stockholm in 1910, and at Toronto in 1913. In 1901 Mr. Hague received the honorary degree of Sc. D. from Columbia University, and in 1906 the degree of LL. D. from the University of Aberdeen. He was a member of the Century and University clubs in New York City, and of the Metro-

politan and Cosmos clubs in Washington. He was married late in life to Mary Bruce Howe, of New York.

Arnold Hague was at all times and under all conditions a gentleman, whether at home, in the social life of the Capital, or about the camp fire in the mountains; considerate of the feelings of others, temperate in language and habits. By nature reticent and reserved, he was conservative in his opinions, cautious in his judgment, and deliberate in action. Possessed of normal human instincts, he nevertheless exhibited admirable self-control under what were at times most exasperating circumstances, as when on one occasion his packer, with camp outfit and mules, deserted him in the mountains and left him to the chance of meeting one of his other parties or of going without food for several days. Mr. Hague encountered one of his assistants the next day; but though he was convinced of the treachery of his own packer, he retained him in his service until the end of the season as the most judicial procedure, it being very difficult to find a substitute at the time.

Mr. Hague was a man of good taste in music and in art, with a fine appreciation of the beautiful in nature, whether the grandeur of mountains, the colors of a sunset, or the somber tones of an autumn meadow. Though undemonstrative by temperament, he occasionally expressed his enjoyment of beautiful scenery and his pleasure in sharing the enjoyment with others in a most effective manner. The writer recalls with emotion the interest Arnold Hague took in conducting his young assistant, with eyes shut, to the brink of the Yellowstone Falls, so that he might have the pleasure of a sudden view of the many-colored canyon beyond. Although Mr. Hague was greatly interested in the preservation of wild animals within the park, he was no sportsman, and said on one occasion that he had never killed any game or fish in his life. He was not averse, however, to his assistants keeping the camp table well supplied.

As a geologist and explorer Hague took a lively interest in discovery, whether a bit of geological structure or the lay of new or little known country. He delighted to follow an elk trail through a difficult region, as well as to unravel a complex piece of stratigraphy; but when he had solved the riddle his interest in it ceased, as he himself has said. He cared little to convey his discoveries to others, and in the matter of opinions or theories he seemed to care less as to what others thought; so that he made little or no effort to influence them, and in consequence was indifferent as to publishing the results of his researches. Moreover, he had high standards, both as regards the character of his work and the mode of its expression in print, and this, in conjunction with his deliberate habits of thought and action, may account for the length of time

required for him to bring his reports to what he considered a proper finish.

As his geological assistant through 12 years of field and office work, the writer can testify to the kindly interest and cordial cooperation of Arnold Hague in the work of the beginner, and the writer wishes to take this opportunity to express his gratitude for valuable advice on critical occasions and for most liberal treatment in the matter of individual research and independent publication of material investigated under the charge of his chief while in the Yellowstone National Park and elsewhere.

The last years of Doctor Hague's life were spent quietly in Washington and Newport, Rhode Island, his health and strength declining gradually. At the Albany meeting of the Geological Society, on a stormy night, when the pavements were covered with ice, he fell and struck his head, losing consciousness for some time. Although he appeared to have recovered from this accident, his death came suddenly the following May, on the fourteenth, in the seventy-seventh year of his age. He was laid to rest in the Albany Rural Cemetery with other members of his family, and near by are the graves not only of his brother James, but of James Hall, Ebenezer Emmons, R. P. Whitfield, Charles S. Prosser, and other men of science.

The spirit of Arnold Hague seems to have been in accord with the tranquillity of a Chinese proverb he was fond of quoting when in the mountains:

> "He who dwells 'midst the turmoil of cities and towns
> Knows not the quiet of rivers and lakes."

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MEMORIAL OF ROBERT HILLS LOUGHRIDGE [1]

BY EUGENE ALLEN SMITH

Robert Hills Loughridge, the son of Rev. Robert McGill Loughridge and Olivia D. Hills, daughter of David Hills, of Rome, New York, was born at Kowetah Mission, Creek Nation, Indian Territory, October 9, 1843, of which mission his father had charge at the time. His mother died when he was about two years old, and his father afterwards married Miss Harriet Johnson, of Sturbridge, Massachusetts, a graduate of Mount Holyoke Seminary and an educated, refined, Christian woman.

When the Tallahassee Mission, larger and better adapted to the training of Indian boys and girls, was established near Muskogee, the mission at Kowetah was abandoned, and the Rev. Mr. Loughridge was assigned to the new station. Here Robert received his early education under the careful and sympathetic direction of his father and stepmother.

When about seventeen years old he was sent to the Synodical College

[1] Read before the Society December 27, 1917.
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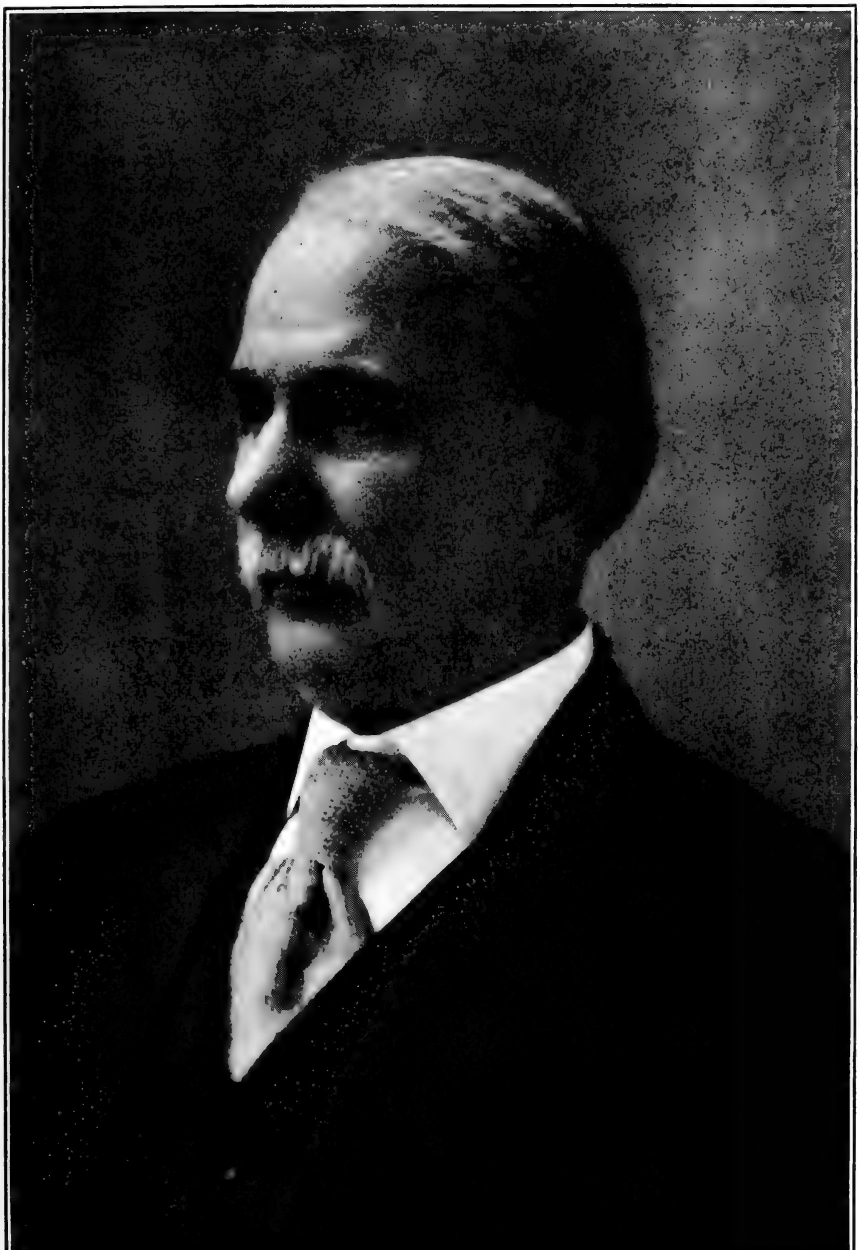

Truly yours
R H Loughridge

at La Grange, Tennessee, where the Rev. John H. Gray was president and Rev. John N. Waddell was Professor of Ancient Languages, both of whom were close friends of his father. Robert had been at the La Grange college little more than a year when the war broke out, and he, along with William C. Gray and George Waddell, his intimate friends, enlisted in the Thirteenth Regiment of the Tennessee Infantry in March, 1862. At the battle of Shiloh, the first in which he was engaged, he was severely wounded in the face and left as dying or dead on the battlefield. Doctor Gray, on learning that his son and George Waddell were safe, but that young Loughridge was missing, went to search for him and found him living, but so seriously wounded that he was unable to talk. He was taken to Doctor Gray's home at La Grange and was there tenderly cared for until he was able to go to the home of an uncle in Mississippi. When somewhat recovered from this wound, the scars of which he retained to the end of his life, he joined the army again and remained in it till the end, though not in active service at the front. At the close of the war he went to Texas, to the home of his father, who had been compelled by the fortunes of war to give up his work among the Indians.

He had one year at school in La Grange, Texas, and afterwards taught for a year in a near-by country school. In 1867, during the epidemic of that year, he had a severe attack of yellow fever and his life was despaired of.

In 1868 he entered the University of Mississippi, at Oxford, of which at that time his former preceptor at La Grange College, Dr. John N. Waddell, was chancellor, and here began his lifelong friendship with Dr. Eugene W. Hilgard.

In 1871 he was graduated from the University of Mississippi with the degree of B. S. After graduation he remained at the university as Adjunct Professor of Chemistry until 1874, taking up in 1873 a line of study looking to the degree of Ph. D., which was conferred on him by the University of Mississippi in 1876. During the period 1871-1874 he served also as Assistant State Geologist of Mississippi under Doctor Hilgard.

From 1874 to 1878 he was assistant on the Georgia Geological Survey, with Dr. George Little as State Geologist. From the Georgia Survey he was called to California by Doctor Hilgard to assist in the preparation of the reports of the Tenth Census on cotton culture. In this work he was engaged until its completion. From 1882 to 1885 he was assistant on the Geological Survey of Kentucky in the preparation of a report on the "Jackson Purchase" region and of a number of counties. Much of the writing of these reports was done at Columbia, South Carolina, where he was Professor of Agricultural Chemistry in the university of that State

from 1885 to 1890. From South Carolina he was called again to the University of California as assistant to his friend Hilgard, and at that institution he remained the rest of his life, as Assistant Professor of Agricultural Chemistry and Agricultural Geology from 1891 to 1908; as Associate Professor of Agricultural Chemistry, 1908 and 1909; and as emeritus professor, 1909 until his death.

He was married October 19, 1886, to Miss Bessie Webb, of New Orleans, who died at their home in Berkeley, January 23, 1895. There were no children by this marriage.

On May 22, 1917, Doctor Loughridge, while on the way to take a train at Berkeley, was seized by an acute attack of heart trouble. After a partial recovery he was taken to the home of his brother, James A. Loughridge, in Waco, Texas, where he died, July 1, 1917. He was a member of the Presbyterian Church, as was his father before him. He was a Fellow of the American Association for the Advancement of Science and of the Geological Society of America; member of the Society for the Promotion of Agricultural Science; of the Forestry Association, and of the American Geographical Society.

From December, 1868, to July, 1871, the present writer was assistant on the Geological Survey of Mississippi, engaged during the summer months in field-work and the rest of the time in making analyses of soils and marls of Mississippi in the university laboratory under the direction of Doctor Hilgard. Loughridge at that time was a student engaged in special chemical work in the same laboratory. In this way I came to know him very well, both as to his personal character and as to his scientific work. When I came to the University of Alabama, in the fall of 1871, Loughridge took up my work with the Mississippi Survey, making numerous soil and marl analyses, afterwards published in the Cotton Culture reports.

Dr. George Little, as State Geologist of Mississippi from 1866 to 1870 and as Professor of Geology in the University of Mississippi from 1870 to 1874, had ample opportunity for becoming well acquainted with Loughridge's work, and when in 1874 he became State Geologist of Georgia he offered the position of assistant on the Georgia Survey to Loughridge, who held the position from 1874 to 1878.

Then came the preparation of the reports on cotton culture for the Tenth Census, which Doctor Hilgard had undertaken at the request of the Superintendent, Gen. Francis A. Walker. Loughridge was immediately called into service by Dr. Hilgard, whose chief assistant he was until the Cotton Culture reports were finished and turned over to the printers, some time in 1882. During these four years Loughridge prepared the

reports on the States of Georgia, Texas, Arkansas, Indian Territory, and Missouri, which necessitated a good deal of field-work in the way of geological examination in all these States.

In the coordination of the State reports, and especially in the adjustment of the general map with the individual State maps, and of the State maps with each other, Loughridge was Doctor Hilgard's main dependence, since he had had personal acquaintance with the geological and agricultural boundaries in most of these States. The soil analyses also, on which Doctor Hilgard laid much stress, were made in the summer and fall of 1880, mainly in the chemical laboratory of the University of Alabama, under the joint direction of Mr. Loughridge and myself, he having oversight of the laboratory during the summer months, which I devoted to field-work in Alabama and Florida, while I had charge of the chemical work the rest of the time, thus liberating Loughridge for his field-work in the different States. In this way most of the chemical analyses of soils of the cotton-producing States, with exceptions below noted, were made. A great number of analyses of Mississippi soils were already available through the work of Doctor Hilgard prior to 1860, and by myself and Loughridge from 1868 to 1874, but it was necessary to supplement these by analyses of soils specially selected by Doctor Hilgard to illustrate certain types which came under discussion. In a similar way, while most of the analyses of soils from the other cotton-producing States were made at the University of Alabama under conditions above described, yet it was found necessary to supplement these by analyses of specially selected soils, and these analyses were carried out by Loughridge at the University of California, whither he was called by Doctor Hilgard to assist in the final arrangement of his great report.

The importance of the assistance rendered by Loughridge to Doctor Hilgard in the preparation of these Cotton Culture reports, can not well be overestimated; for, in addition to writing the reports of the five States above named, he conducted a large proportion of the correspondence of Doctor Hilgard with the special agents in charge of the several States, necessary for the proper correlation of the individual State reports and their adjustment as parts of a consistent story of cotton culture in the United States. Besides the analyses of selected soil types, he made many special *humus* determinations for this report. In a word, there was no one else who could have carried out the investigations needed by Doctor Hilgard to make his report the complete monograph which he had planned.

After all the manuscripts of the Cotton Culture reports were in the hands of the printers Doctor Loughridge accepted a position with the

Kentucky Geological Survey, which he held until 1885. His first work there was on the geology and agricultural features of the "Jackson Purchase" region of Kentucky, embracing descriptions of five counties. This report was published in 1888. His report on Clinton County, Kentucky, was printed in 1890, but his manuscripts of similar reports on Livingston County and on Meade County were turned over to the State Bureau of Mines, on the suspension of the Geological Survey, and have never been printed.

For the next five years, from 1885 to 1890, Loughridge was Professor of Agricultural Chemistry in the University of South Carolina, at Columbia. During this time he contributed several articles to the reports of the experiment station.

Returning to California in 1891, he again became Hilgard's valued assistant and associate in the study of the soils and agricultural conditions of California. Some of these investigations were conducted jointly with Doctor Hilgard, but most of them independently, though generally along the lines of Hilgard's researches and often at his suggestion. At the time of his death he was engaged in the preparation for publication of a large amount of data collected by himself, Doctor Hilgard, and other members of the Department of Agriculture of the University of California.

The quotations given below, from friends who have known him most intimately, will perhaps best set forth the personality of Doctor Loughridge and his character.

Dr. David P. Barrow, chancellor of the University of Georgia, who was intimately associated with Doctor Loughridge when they were both connected with the Geological Survey of Georgia, writes concerning him:

"I was impressed with his quiet manner and his orderliness in all that he undertook. It seemed to me, that he was very precise as a boy, I thought too much so, but I learned from him somewhat of the value of system, and a great deal of the strength which may be under a quiet, diffident manner.

"He taught me something of the amount one may accomplish by saving scraps of time. I do not recall any one with whom I have associated who was quite so careful of time as was Doctor Loughridge. He was always on a high plane in conduct and in his talk."

One trait of his character which commanded the admiration of his friends was his devotion to Doctor Hilgard, with whom he was closely associated from his early manhood. This friendship and his unselfish cooperation were fully appreciated by Doctor Hilgard, from whom we quote the following paragraphs published in the University of California Journal of Agriculture of May, 1915:

"During a lifetime devoted to research and instruction in agricultural science, Dr. R. H. Loughridge has most comprehensively redeemed the promise

I first recognized in him while he was a student at the University of Mississippi. His patient, accurate, and persevering work, especially in soil chemistry and physics, always guided by a quick perception and keen appreciation of the problems to be solved, has received wide recognition both at home and abroad. Doctor Loughridge's early work on the various sediments obtained in physical soil analysis, his extended physico-geographical studies on cotton culture, in connection with the United States Tenth Census, and his latest investigations of soil columns representing California agricultural regions, alike testify to his conscientious habit and broad concept of research work, and to his modesty in claiming credit."

From a statement in memory of Doctor Loughridge, printed in the University of California Chronicle, Volume XIX, number 4, we make the following extract as a fitting close to this memorial:

"Specifically, some of the studies which engaged Doctor Loughridge's attention were the following: Chemical and mechanical analyses of typical arid soils of California; studies of the nature, movements, and effects of alkali salts in soils; and investigations on moisture movements under systems of irrigation. In all his work he had become accustomed from his youth to seek the advice and assistance of his colleague, Professor Hilgard, whose problems became his. The long and remarkable devotion which Professor Loughridge evinced for his teacher and friend is an instance of a rare attachment of man to man which in our workaday world is ever a source of wonder. Wholeheartedly and deeply devoted to his masterful and distinguished colleague and friend, he was content to labor humbly at his task in furtherance of the researches which Hilgard planned, elaborated, and rendered celebrated.

"A modest, gentle, and devoted character, generous to a fault, and always a gentleman, was our late colleague, Robert Hills Loughridge. He had learned to regard the 'world and his neighbor' with a smile and to take his part unostentatiously in its ever-changing drama. *Requiescat in pace.*"

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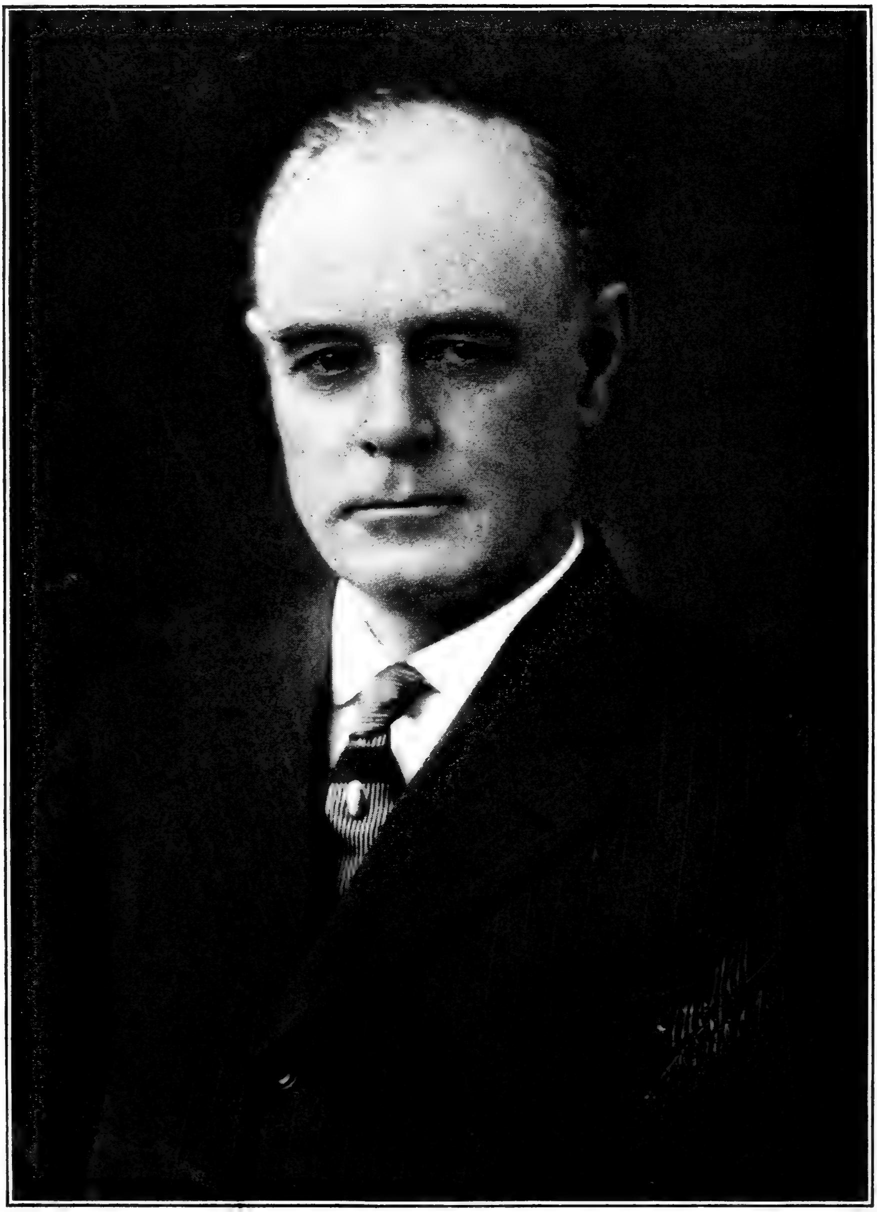

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MEMORIAL OF ALBERT HOMER PURDUE [1]

BY GEORGE H. ASHLEY

Albert Homer Purdue, late State Geologist of Tennessee, was born March 29, 1861, in Warrick County, Indiana, near Yankeetown—a small village in the loess-covered hills bordering the Ohio River—an hour's

[1] Read before the Society December 27, 1917.
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ride by trolley east from Evansville. While the people of the town came, as a rule, from Yankeeland, one of Mr. Purdue's grandfathers had been an early settler in western middle Tennessee. His early education was obtained at Yankeetown and later at the Indiana State Normal School at Terre Haute, from which he graduated in 1886. In 1886-1887 Mr. Purdue taught at Sullivan, Indiana. In 1887-1888 he was superintendent of public schools at West Plains, Missouri. In 1887, at Indianapolis, Indiana, he married Miss Bertha Lee Burdick, who died of consumption a year later. From 1889 to 1891 he was assistant superintendent of the United States Indian School at Albuquerque, New Mexico. Part of his duties were the selection of children from the reservation for the school and the rounding up of boys who had run away—a line of work that led to many interesting experiences. From 1891 to 1894 he was at Stanford University, from which he obtained the degree of A. B. in 1893. While there he made geologic studies on the San Francisco Peninsula, and during 1892-1893 was an assistant geologist for the Arkansas Geological Survey with the writer, studying the southern part of the Ouachita uplift. This association with Purdue in the field during the summer and fall of 1892 was one of the pleasantest epochs in the writer's life. We were living on the country, in a region but little settled at that time, and Purdue's vivid description of his week's experience, when we got together at the end of each week, gave an air of romance and adventure to the whole undertaking. This work and that in the Coast Range Mountains of California, both under the eye of Branner and with his counsel, Purdue counted as among the most valuable training experiences he could have had, as he could not help getting somewhat of Branner's broad point of view and critical study of details. In 1894, after a year of graduate work at Stanford, he became a candidate for the elective position of State Geologist of Indiana; but his long absence from the State had put him out of touch with the political personnel of the Republican party and he failed to get the nomination. Perhaps he would have succeeded if he had listened to the demands of those who wished the promise of places which they were not prepared to fill. The winter following he was principal of the high school at Rensselaer, Indiana. Then came a year of graduate work as a Fellow at the University of Chicago.

His professorial career began in 1896, when he was elected Professor of Geology at the University of Arkansas, his position after 1902 being that of Professor of Geology and Mining. Here his executive ability and judgment were early recognized, and as time went on more and more of the administrative committee work of the university fell on his shoulders. He was chairman of the Committee on Student Affairs and of the Classi-

fication Committee, which had in charge the arrangement of courses, etc. In 1898 he married Miss Ida Pace, of Harrison, Arkansas, at that time Associate Professor of English at the university—a woman of unusual mental and social attainments, who comes of a family distinguished in the life of Arkansas. In 1895, again in 1901, and from then on Mr. Purdue was a field assistant on the United States Geological Survey, devoting his summers to field-work. With the Survey he had the reputation of being one of the very few teaching geologists whom that organization could count on to carry out a program not only in the field, but in the office preparation of his reports. At the time of the Saint Louis Exposition he was made Superintendent of Mines and Metallurgy for the State. In 1907 Mr. Purdue was made State Geologist *ex officio* of the Arkansas Survey. Though having at his disposal only very meager funds, Purdue was able to prepare or have prepared a number of highly creditable reports, including one on the slates of the State, by himself; one by Prof. W. N. Gladson on the water powers of the State, and one by Prof. A. A. Steel on mining methods in the coal fields of the State.

As a teacher, Purdue brought to his work the results of his normal-school preparation, and the training received under Branner and J. P. Smith at Stanford, and Salisbury, Chamberlain, and others at Chicago, together with his own rather varied experience along that line. He was not a believer in the lecture method of instruction, but rather in the students working out their results under the stimulus of actual contact with the problems in the field and laboratory, and in this knowledge being reinforced by repeated review and by application to new and practical problems. He had little regard for the student who would not work and he would bar such students as much as possible from his classes. The great energy he put into his teaching in both the class-room and field wonderfully impressed his students and assistants, so that he constantly inspired them to obtain greater results and attain higher ideals. When he left the University of Arkansas the students presented him a silver loving cup as a token of the respect they held for him as a teacher. His students speak of his class-work being as good as any course in logic, as he led them to analyze their data and taught them how to draw proper conclusions therefrom; so that, aside from those who decided to take up geology as a profession, his old students, scattered all over the United States, look back to the work in his classes as one of the most profitable experiences of their university life. Among his students who were led into adopting geology as a life work may be named Miser and Mesler, of the United States Geological Survey; Carl Smith, Munn, McCreary, Hutchinson, and others, who after more or less time spent with the

national organization have gone into consulting or professional work in the oil industry.

Purdue had great faith in the constructive ability of the boy brought up on the farm, in which class most of his students fell, and in a talk a few years ago he explained the reason for that ability as due to the constant association in labor of father and son on the farm, the son getting the advantage of the father's example and counsel as they worked together in the fields or gardens, and thus acquiring ideals of industry, efficiency, and initiative commonly lacking in the city or town bred boy.

In 1912 Mr. Purdue was elected State Geologist of Tennessee, which position he filled with honor to himself and the State until his death, on December 12, 1917. Of his success as State Geologist of Tennessee the best testimony is the steady stream of high-grade publications that flowed from his office. Equally convincing from another direction is the fact that during the session of the last State legislature his work and its value to the State received unstinted praise, and the enlarged appropriation for the work of the Survey went through practically without question or opposition.

Purdue had for thirty years suffered at times from intestinal trouble that had proved more and more of a handicap as time went on. Last spring, after a winter of unusual demand, he suffered a sudden attack of this old trouble, which for a time undermined his health and threatened to require an immediate operation. A number of trips to the field and for rest led to his regaining somewhat his old vigor, though not entirely.

The last week of November he made an automobile trip into east Tennessee for the purpose of studying the manganese deposits of that region. He became so ill that he stored his car and returned to Nashville by railroad. He was taken immediately to a local hospital, and after a few days underwent an operation, with the hope of having his health restored. The morning of the operation he dictated for publication in the Resources of Tennessee a paper giving the results of his recent investigation of manganese. Then he walked into the operating room as calmly as if he were going into his office for a day's work. At first everything indicated a speedy recovery, but complications arose and he died a week later from uremic poison.

Mr. Purdue was quiet and unassuming—a man who disliked display, who sought always to keep his own personality and achievements in the background, yet a man who made friends that stuck, because he could prove himself a true friend under all circumstances; a man whose judgment was sought by many; a man whose influence was always for sanity, for uplift, for scientific accuracy, even in the simple things of life. I

still remember that when we were working together in the mountains of Arkansas, it was my method to fall into the ways of the people with whom we were living, especially in adopting the vernacular of the region—a habit to which Purdue always objected and for which he often chided me. He would insist that, as educated men, we had no right not to give the mountain people a glimpse of correct English. This same regard for the Queen's English is seen in the painstaking care with which he edited all of the manuscripts published by him as State Geologist.

As a field geologist, Purdue was tireless, painstaking, and thorough, and the same energy and careful attention characterized all of the preparation of his reports. This desire for high quality and accuracy doubtless reduced somewhat the number and length of papers prepared by him, but his work made up in quality what it lacked in volume.

While he was at the University of Arkansas he spent the summer months in the field in that State—most of the time in camp with a party of from one to three of his students—and wrote his reports at odd moments during the school year. Although his field-work was varied, it consisted mainly of detailed areal mapping for the United States Geological Survey in a number of quadrangles in the northwestern and west-central parts of the State. Whenever funds were appropriated by the Arkansas legislature for the State Survey he made it count as much as possible by cooperating with the United States Geological Survey. Most of his geologic work in Tennessee was administrative, but he found time to make numerous short field trips into different parts of the State. Much of the work carried on under his administration as State Geologist in that State was done in cooperation with the United States Geological Survey and the United States Soil Survey.

Among his more important papers are the Winslow and Eureka Springs-Harrison folios and the De Queen-Caddo Gap and Hot Springs folios, awaiting publication; the slate deposits of Arkansas, besides a large number of shorter publications issued by the United States Geological Survey, State Surveys of Arkansas and Tennessee, and many others published in magazines or elsewhere. Considering the large amount of administrative work in the University of Arkansas that fell to his lot, this is a rather remarkable showing of scientific results for a teaching professor occupying practically the whole bench of geology.

Mr. Purdue was a member of the American Institute of Mining Engineers, the Indiana Academy of Sciences, the National Geographic Society, and the Seismological Society of America. He was a Fellow of the American Association for the Advancement of Science, the Geological Society of America, and the Geological Society of London. He often

attended the meetings of State Geologists, of the Conservation Congress, and of the Southern Commercial Congress. While at the University of Arkansas he was made a teacher member of the Kappa Alpha fraternity. In 1907 he was elected to the Stanford chapter of Sigma Xi. The commencement following his resignation as Professor of Geology at the University of Arkansas that institution conferred on him the degree of LL. D. There was no recognition that he prized more highly than his election, in 1911, to the Council of the Geological Society of America. He was President of the Tennessee Academy of Sciences at the time of his death and was already considering possible subjects for the next annual address.

As a citizen, Mr. Purdue was always public-spirited, entering in large degree into the life and activities of the place of his home and of the State at large. In Nashville, besides his interest in the Commercial Club he was active in other civic and social clubs, including the Rotary, Freolac, Tennessee Historical Society, Nashville Engineering Society, Reynolds Lodge, Knights of Pythias; Phœnix Lodge, Free and Accepted Masons, and was a generous subscriber to the work of various organizations. His home, with two boys now of college age, was always a place for real Southern hospitality, for Purdue had a large sense of humor and a live personal interest in the welfare of all of his friends, and a wife whose intellectual attainments and personal charms not only added to the welcome of the home, but were a constant inspiration to the man.

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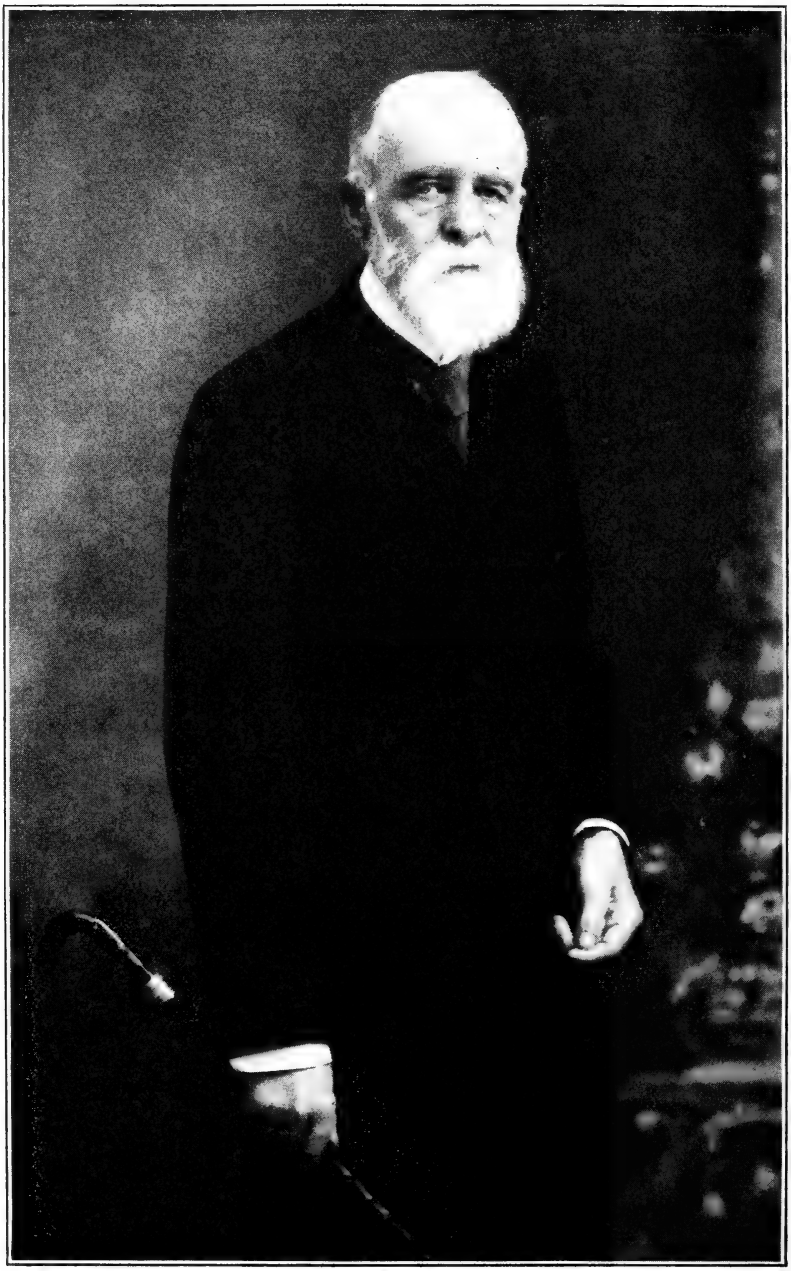

Very sincerely yours
Henry M. Seely

MEMORIAL OF HENRY MARTYN SEELY [1]

BY GEORGE H. PERKINS

Henry Martyn Seely was born in South Onondaga, New York, on October 2, 1828. He died in Middlebury, Vermont, May 4, 1917, in his eighty-ninth year. He fitted for college at Cazenovia Seminary and entered the Sheffield Scientific School of Yale University, from which he graduated with the degree of Bachelor of Philosophy in 1856. During several following years he continued his studies at Yale and received the degree of Master of Arts in 1860. He was Professor of Chemistry in the Berkshire Medical Institute from 1857 to 1862, receiving from that institution the degree of Doctor of Medicine.

From 1860 until 1867 he was non-resident Professor of Chemistry in the Medical Department of the University of Vermont. In 1867 Professor Seely went to Germany and studied for two years at Freiburg and Heidelburg. He was elected Professor of Chemistry at Middlebury College in 1861 and, excepting the two years abroad, he lived in Middlebury until his death—that is, for fifty-five years.

In 1858 he married Miss Adelaide Hamblin, of Perryville, New York, who died August 25, 1868, leaving a daughter, now Mrs. John Chapman, of Anvik, Alaska. Two years later he married Miss Sarah J. Matthews, of Fair Haven, Vermont, who is still living. Three children of this marriage are Mrs. John M. Thomas, Middlebury, Vermont; Dr. Henry H. Seely, Harvard, Nebraska, and Locke M. Seely, Newark, New Jersey.

Professor Seely was for four years, 1875-1878, secretary of the Vermont State Board of Agriculture. The duties of this office called him to visit many of the towns of the State, where he arranged meetings in which subjects of practical interest to farmers were helpfully discussed. In this connection, Professor Seely edited three volumes of reports which are highly valued by the farmers of the State.

While he was never active in politics, his well known and very pronounced temperance principles caused his nomination, in 1886 and again in 1888, for Governor by the Prohibition party of Vermont.

He continued active work as professor at Middlebury until 1895, when he retired as professor emeritus. But his interest in his chosen studies did not cease so long as life lasted.

Though teaching, with geology, several other branches of science during most of his life at Middlebury, he became during the latter years

[1] Read before the Society December 27, 1917.
Manuscript received by the Secretary of the Society December 14, 1917.

more and more devoted to geology, and toward the last his whole attention was given to that science.

The many and often perplexing problems presented by the rocks of the Champlain Valley were ever in his thoughts and eagerly discussed whenever occasion offered, even to the very last; for though his bodily strength failed, so that for the last few years of his life he could not engage in the field-work of which he was so fond, his mind lost none of its wonted grasp of such problems.

Of his work in Middlebury, Dr. John M. Thomas, who as student and close friend is more competent to speak than the writer, says:

"During the thirty-four years in which he was actively engaged in teaching at Middlebury he taught chemistry, which was the chief subject in which he had fitted himself, but also geology, botany, zoology, for the most of the time without assistance, but was himself the sole instructor. Except the last few years, the course of study in the college was required, and every student from the class of 1861 to that of 1891 was under Professor Seely's instruction in all of the above branches. When the elective system was introduced in 1891, electives were few and Professor Seely's courses were taken by nearly every student."

Of Professor Seely as teacher, Doctor Thomas adds:

"The kindliness and gentleness of the man, his sweetness and grace of disposition, were perhaps the first qualities in his teaching, as they were first in the thought of any who were brought into relation to him in any way.

"Students are often severe judges, and I am sure that no student ever questioned the Christian character of Professor Seely. He employed his Christianity in the class-room as thoroughly as he did out of it. At the same time he was a thorough and careful teacher of science. He had learned the methods of scientific investigation in Germany and his work was never superficial nor merely didactic.

"So far as facilities allowed, he employed laboratory methods even in the years when they were not general. He continued to hold ideals of specialization and research which he was not privileged to carry out, but he imparted the spirit and the knowledge of the goal to his disciples.

"A patient, kindly, gentle man, he is remembered with peculiar affection and honor by a large proportion of the living graduates of Middlebury College as a teacher for whose Christian character and for whose zeal they are alike grateful."

Professor Sanford, who for several years was a colleague with Professor Seely at Middlebury, writes:

"One characteristic of his teaching seemed to be a love for a plain setting forth and an avoidance of a spectacular method of approach. He never, so far as I know, cared to arouse or stimulate curiosity or flagging attention by novel or unusual forms of presentation of the subject, thinking that a simple recital of the laws that governed the whirlwind, or the rainfall, or the story

implied in the fossil, or the beauty of the corolla or cell structure was in itself enough to arouse interest and awaken appreciation and enthusiasm. His own simple, but forceful manner in the exposition of natural phenomena showed the students that he was no listless teacher of great truths."

As to Professor Seely's disposition, Doctor Sanford well remarks:

"If ever there was in the village in which he lived a beloved son of Teuthras who lived by the road and was glad to be a friend of man it was he."

As comrade and fellow-worker in the field, the writer enjoyed the close acquaintance of Professor Seely for more than forty years, and he can most heartily indorse all that has been said concerning his character and ability as a teacher, and I may add testimony as to his unfailing patience and thoroughness as a field-worker.

Most of our investigations were carried on in the Champlain Valley, and the numerous and varied problems which this region presents to any who will see them affords great delight as well as perplexity to those who would know its geology. The writer considers it as one of the great privileges of his life to have been the intimate companion of such a man and with him to have sought to bring some sort of order out of the confusion of the beds of the Champlain Valley.

To all students of western Vermont and eastern New York the work of Professor Seely must always be of greatest importance. This is notably true of the Beekmantown and Chazy, and in this connection it would be quite unfair not to speak of Dr. Ezra Brainerd, who for some years was coworker with Doctor Seely in establishing a system of classification for these beds which must always be classic in geology and form a foundation for whatever may follow as a result of future studies. The names of Brainerd and Seely will always be inseparably associated in the minds of students of the Beekmantown and Chazy of the Champlain Valley.

An important addition to our knowledge of the life of the Beekmantown was made when Dr. R. P. Whitfield described and figured in the bulletins of the American Museum of Natural History many new species of cephalopods and other mollusks which these gentlemen had secured from the limestone beds of Fort Cassin at the entrance of Otter Creek into Lake Champlain. Addison County, in which Professor Seely had spent so large a part of his life, was naturally his especial field of work, and the last scientific work which he was able to undertake was an extensive article for the Seventh Report of the Vermont State Geologist, in which he summarized the labors of many years of field-work.

Professor Seely was a Fellow of the Geological Society of America, the Paleontological Society, the American Association for the Advancement

of Science, the American Chemical Society, Biological Society of Washington, and Vermont Botanical Club.

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In cooperation with Dr. Ezra Brainerd:

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Reports of committees were then called for. These were presented as follows:

REPORT OF COMMITTEE ON PHOTOGRAPHY

The collection of photographs belonging to the Society is stored in my office, in room 2209, new Interior Department building, F and G, 18th and 19th streets, Washington. Visiting members occasionally examine the pictures to obtain illustrations for text-books or special articles. There have been no accessions for several years.

NELSON H. DARTON, *Committee.*

ANNOUNCEMENT FROM COMMITTEE ON THE GEOLOGICAL MAP OF BRAZIL

The Secretary reported that Prof. Bailey Willis had written in behalf of the Committee on the Geological Map of Brazil to the effect that the map, by J. C. Branner, is practically ready for publication, together with its accompanying English text and bibliography.

After listening to several announcements regarding the meeting, the Society proceeded to the consideration of scientific papers.

TITLES AND ABSTRACTS OF PAPERS PRESENTED AT THE MORNING SESSION AND DISCUSSIONS THEREON

REPORT OF THE GEOLOGY COMMITTEE OF THE NATIONAL RESEARCH COUNCIL

BY JOHN M. CLARKE, *Chairman*

(*Abstract*)

An elaborate report, with abundance of charts and tabulations of the materials suitable for rapid highway construction and fortification building from

Maine to Texas and extending 100 miles back from the Atlantic coast, has been made and submitted to the Council of National Defense. Geological surveys and maps of the various cantonments are in course of preparation. The special committee on war minerals, organized through the National Research Council, has instituted and carried through surveys in various parts of the country for emergency mineral supplies, and has summarized its work in the form of a congressional bill recommending the appointment of a Minerals Administrator, who shall have control of the entire mineral production of the country.

Other phases of the committee's work were referred to and its further progress along various lines intimated.

Presented in abstract from notes.

Doctor Clarke was followed by Dr. Edward B. Mathews, who outlined briefly what had been accomplished by the Geology Committee's Subcommittee on Roads.

POSTGLACIAL UPLIFT OF NORTHEASTERN AMERICA

BY HERMAN L. FAIRCHILD

(*Abstract*)

Uplifted marine shores have been determined at many stations in Quebec, New Brunswick, Nova Scotia, Maine, and New Hampshire during the past field season. With the large amount of precise data distributed over the wide area and the help from published observations of other geologists, it is now possible to map with at least approximate truth the uplift of northeastern America since the removal of the latest ice-sheet. The lines of equal uplift (isobases) have been extended from the area of New York and western New England, where long study has given definite knowledge.

The criteria chiefly used for determination of summit water level are the deltas, especially of south-flowing streams. The heavy, conspicuous deltas are used for approximate levels, while deltas of small streams and other shore features of the vicinity are relied on for more precise determination. Caution is necessary to avoid confusion with glacial waters.

It appears that the center of uplift lies between Quebec City and James Bay, in amount over 1,000 feet. The amount of uplift found by Daly and others in Newfoundland, with the position of isobases, confirms the opinion of former students that the island, and perhaps Nova Scotia, were independent centers of glaciation. The map suggests that the Mississippi Valley experienced some uplift earlier than that recognized in the Michigan and Erie basins.

Read in abstract from manuscript.

Discussion

Mr. Frank Leverett called attention to evidence that the uplift may have another dome west of James Bay, but he is not able to form any conclusions as to its relation to ice weighting.

Mr. W. Elmer Ekblaw remarked: I wish to state that another center of postglacial uplift is probably located in Greenland or Ellesmere Land. The reports of nearly every expedition to those lands call attention to the raised beaches and wave-cut terraces along the coast. Wegener, geologist of the East Greenland Danish Expedition, speaks of such a beach on the northeast coast of Greenland more than 650 feet above sealevel. Schei speaks repeatedly of the raised beaches along the west coast of Ellesmere Land and the east coast of Axel Heiberg Land. Attention has many times been called to the numerous raised beaches of West Greenland and East Ellesmere Land.

PALEOGEOGRAPHY OF MISSOURI

BY E. B. BRANSON

The author presented a series of maps representing various seas which have occupied Missouri during geologic time and discussed some of the more important sedimentary breaks.

Presented in full extemporaneously.

The Society adjourned soon after noon and reconvened at 2.30 p. m., with President Adams in the chair, and proceeded according to the printed program.

TITLES AND ABSTRACTS OF PAPERS PRESENTED AT THE AFTERNOON SESSION AND DISCUSSIONS THEREON

SUBSIDENCE OF REEF-ENCIRCLED ISLANDS

BY W. M. DAVIS

(*Abstract*)

Darwin gave two kinds of evidence in supporting his theory of upgrowing coral reefs on intermittently subsiding islands: First, his theory replaced unexplained confusion by reasonable order; second, it accounted for the systematic distribution of the reefs known in Darwin's time. Dana added the important independent confirmation given by the embayed shorelines of reef-encircled islands. Additional verification of subsidence is found (1) in the physiographic interpretation of the slopes of reef-encircled islands, which gives a much better estimate of reef thickness than the depth of barrier reef lagoons; (2) in the geological interpretation of the unconformable contacts of reef limestones elevated or at sealevel, with their eroded foundations; this important matter has been very generally neglected; it applies especially to the unconformable fringing reefs of the Philippines, admirably shown on recent Coast Survey charts; (4) in the natural explanation of the disappearance of the detritus that has been eroded from the central islands of barrier reefs; the volume of the detritus is in some instances from 30 to 80 times as great as the volume of the reef-inclosed lagoon; (5) in the absence of reefs on coasts of emergence; (6) in the unequal depths of lagoons and submarine banks.

A liberal measure of subsidence being thus indicated by various lines of

evidence, it remains to consider whether the subsidence has been due to the depression of broad areas of the ocean floor or to relatively local subsidence of the reef foundations, which in most cases are volcanic islands. A broad subsidence of the ocean floor would lower the ocean surface and presumably cause the emergence of marine strata around the greater part of the continental margins. The local subsidence of many volcanic islands, on which reefs are built up as the islands subside, would leave the ocean surface somewhat higher than it was before the islands were formed, and this would tend to raise the ocean on the continental margins and to embay their shorelines. As continental shorelines are very generally embayed, this evidence, as far as it goes, indicates that the subsidence which gave opportunity for reef upgrowth was relatively local. Confirmation is thus found for the suggestion recently made by Molengraaf that the subsidence of volcanic islands is an isostatic phenomenon.

Presented by title in the absence of the author.

STRUCTURE OF SOME MOUNTAINS IN NEW MEXICO

BY N. H. DARTON

(*Abstract*)

In a detailed investigation of the red beds of New Mexico the author has had opportunity to observe the structure of various mountain ranges, especially in the central, eastern, and southern parts of the State. A great variety of interesting details are presented, but faulted tilted blocks are the most numerous. Physiographic features are in part dependent on structure and in part independent of it, excepting so far as to influence the altitude and distribution of hard and soft rocks.

Read by title in the absence of the author.

IMPORTANCE OF NIVATION AS AN EROSIVE FACTOR AND OF SOIL FLOW AS A TRANSPORTING AGENCY IN NORTHERN GREENLAND

BY W. ELMER EKBLAW [1]

(*Abstract*)

Nivation is one of the most important erosive factors in northern Greenland. Especially is this true where the wind piles the snow in drifts.

Dome-shaped drifts of snow form on plateaus, plains, and most comparatively level surfaces; "piedmont" drifts form along cliffs; "wedge" drifts form in gullies and small gorges near the top of cliffs. Each of these drifts produces different results. The dome-shaped drifts result in horizontal solifluction and altiplanation terraces; the piedmont drifts result in solifluction slopes, and "wedge" drifts initiate cirques. These "wedge" drifts may develop into glaciers, or they may develop into circular "piedmont" drifts, as the gorge gradually changes into a cirque. In this latter case the snow completes the formation of the cirque.

[1] Introduced by W. S. Bayley.

Aside from the presence of an ice-table, snowfall is probably one of the essential conditions prerequisite to solifluction in high latitudes. Snowfall and gradual, but not rapid, melting of the snow make solifluction possible.

Distinction should be made between solifluction which causes progressive motion of surface materials, such as results in altiplanation terraces, solifluction slopes, and soil-streams or soil-glaciers, and that which causes only circulatory movement, such as results in "polygonboden." It is the first of these forms of solifluction which is one of the most important transporting agencies in northern Greenland. On every land area of the ice-free coast the landscape presents evidences of the wide-spread activity of this agency.

Read in full from manuscript.

PRESENT STATUS OF THE PROBLEM OF THE ORIGIN OF LOESS

BY C. W. TOMLINSON [1]

(*Abstract*)

A critical analysis of existing opinions on the origin of loess, with a summary of the evidence thus far presented, the conclusions derived therefrom, and suggestions for further study.

Presented in full extemporaneously.

DISCUSSION

Mr. FRANK LEVERETT spoke of the advisability of restricting the term loess to wind deposits of uniform texture and not to include wind deposits in which sand and silt are mingled.

Dr. J. L. RICH: Inasmuch as ants and several kinds of burrowing animals are constantly bringing sand and small pebbles to the surface from depths of two or three feet, it seems to me that any thin deposit of loess, three feet or less thick, would almost certainly be a mixture and would contain considerable coarser material, even if deposited as fine, wind-borne dust, and therefore that a distinction on a genetic basis between this and true loess, such as is suggested by Mr. Leverett, can not be made.

Dr. A. R. CROOK: I should like to inquire if there are many data concerning the per cent of solubility of loess in hydrochloride and in various parts of the world, since this would shed light on the source or distance of transportation of the material constituting the loess.

Mr. J. H. LEES: Professor Shimek shows in Iowa Academy of Science, volume 24, that there probably is no loess in Bohemia. The material which has been called loess by the Bohemian geologists is waterlaid and the geologists themselves are now of the opinion that it is not true loess.

Mr. W. H. BUCHER: On the sides of the Rhine Valley graben the mixed character of the loess is in numerous exposures seen to be intimately connected with the proximity to hill and mountain slopes from which rain occasionally washed pebbles and talus material on top of growing loess deposits. Such material, although transported by water, only emphasizes the subaerial

[1] Introduced by Eliot Blackwelder.

origin of the bulk of the deposit. At such localities not uncommonly faunules of land gastropods are found in the loess, consisting of characteristically moisture-loving, forest types which are in pronounced contrast to the typical loess fauna which is generally considered to point to treeless, more or less steppe-like, vegetation. That even under present climatic conditions the winds in that portion of the Rhine Valley are competent to carry on the deposition of loess is indicated by the fact that repeatedly during exceptional storms in summer-time dust lodges in conspicuous quantity on the roof of the astronomical observatory at Heidelberg, at an elevation of some 1,500 feet above the plain, on top of the forest-covered slopes of the faultscarp.

LATE PLEISTOCENE SHORELINE IN MAINE AND NEW HAMPSHIRE

BY FRANK J. KATZ

(*Abstract*)

In the coastal region of southwest Maine and southeast New Hampshire there are uplifted beaches and deltas which lie higher than late Wisconsin marine clay deposits in their immediate vicinity. The beach phenomena, including wave-cut cliffs, wave-built terraces, and sand and cobble bars built on what were evidently prominently exposed islands and headlands, are strongly developed. A group of notable features of this character in Rockingham and Strafford counties, New Hampshire, and York County, Maine, and a second group in Cumberland County, Maine, were examined and their elevations were determined. Deltas in the valleys of Isinglass, Cocheco, Mousam, Ossippes, Saco, and Little Androscoggin rivers were also examined and found to lie at elevations accordant with those of the beaches. In height the beaches range from 155 feet in Stratham, New Hampshire, to 300 feet in Pownal, Maine, and the deltas from 200 feet in Dover, New Hampshire, to 300 feet in Paris, Maine, and all are coincident with an approximately plane surface, sloping five to six feet to the mile in a direction 40° east of south—in other words, the isobases trend north 50° east, approximately parallel to the general trend of the north shore of the Gulf of Maine. The 300-foot isobase passes through Milton, New Hampshire, and the 200-foot isobase through Dover, New Hampshire, and South Portland, Maine. If the slope is constant, the isobase zero is in the vicinity of Salem, Massachusetts. In this territory many allied features have been noted but not closely examined, nor have their elevations been reliably determined. It is plain that some of the shoreline features in the region fall below the surface indicated above, and it is also certain that none of them are higher.

The result here announced does not accord with the eastward extension of the amount of uplift and the altitude of the uplift marine plane advocated to explain the phenomena in the Connecticut River valley and the Long Island region. However, conclusions for the two regions are not irreconcilable, if it can be established that the wave of uplift that followed the withdrawal of the ice approximately parallel the continental border, or, what amounts to the same thing, if there was a local center of uplift around which the isobases curve.

Read by title in the absence of the author.

GLACIAL LAKES OF SAGINAW BASIN IN RELATION TO UPLIFT

BY FRANK LEVERETT

(*Abstract*)

By the aid of topographic maps with 5-foot contours, it has been found that the higher beaches—Saginaw and Arkona—in the Saginaw Basin have been uplifted northward, but that the low beach of Lake Warren, formed at a later time, has not been uplifted in this area. It is, however, tilted in neighboring ports of Michigan to the north. The area of uplift thus became reduced on the south during the Glacial epoch. Similar phenomena have been observed in the Huron-Erie Basin and are discussed by Taylor in Monograph LIII, United States Geological Survey.

Presented in full extemporaneously.

MECHANICS OF LACCOLITHIC INTRUSION

BY CHARLES R. KEYES

(*Abstract*)

Between the two extreme views concerning the genesis of laccolithic mountains, between the idea of an easily floated prism of strata that expands into a symmetrical, dome-shaped earth-blister, and the notion that the phenomenon is a mechanical impossibility, there now develops midway a strictly tectonic conception which, although making improbable the one and perfectly invalidating the other, is amply supported by recent wide observation, and withal is mathematically sound. It turns out that the genetic impetus in its nature is dominantly orogenic rather than simply hydrostatic.

In the Sierra del Oro, or Gold Mountains, of New Mexico, of which the Ortiz group is the best known, the structural relationships of laccolithic intrusion are especially well displayed. The ideal form of the laccolithic mass is shown to be not a symmetrical lens, but a wedge-shaped body in which a fault-plane constitutes the flat, thick base.

A laccolithic mountain is not fortuitously located. In order that a laccolith be produced, rather than any other form of volcanic manifestation, it seems that the intrusive mass must have a particular tectonic setting. Profound faulting is one of the prime factors. Another is orographic flexing by which the rigidity of certain arching strata potentially carries or largely sustains the load of superincumbent beds. Probably the unusually high viscosity of acidic magmas has an important, but as yet uncalculated, influence on events. The four laccoliths of the Sierra del Oro are situated at equidistant points, where recently formed folds intersect at an angle of 45° a notable line of ancient displacement. Like circumstances may obtain for all laccoliths.

A laccolith is not a locally thickened sill. The two masses are formed under entirely different physical and tectonic conditions. They are genetically distinct and perfectly unrelated.

Read by title in the absence of the author.

FACETED FORM OF A COLLAPSING GEOID

BY CHARLES R. KEYES

(*Abstract*)

It is not necessary to postulate a cooling globe in order to consider the geometric effects of partial collapse. Because of the fact that with a given mass the body with the greatest surface area is the sphere, and the one with the least surface a four-sided form, it is sometimes thought that our planet is tending toward a tetrahedral earth. It is finally indicated that the crystallographic form could hardly be so simple, but a shape in which each face of the ground-form consists of a number of smaller facets. The rhombic dodecahedron best fits the figure which the great mountain chains outline on the surface of the globe.

In recent experiment, bearing directly on this theme, made with heavy rolled paper, the amount of collapse is measured by the diurnal change in the humidity of the air. On dry days the result is a surface of singularly large and perfect rhombohedrons. With paper not so tough relatively, or with the use of some brittle substance, no doubt rupture would have taken place along the edges of the facets. In all practical respects the lines of the great mountain upheavals on the earth are exactly located in miniature.

Read by title in the absence of the author.

CHARACTERISTICS OF THE UPPER PART OF THE TILL OF SOUTHERN ILLINOIS AND ELSEWHERE

BY EUGENE WESLEY SHAW

(*Abstract*)

In 1909, while surveying the Murphysboro quadrangle, Illinois, the writer gained the impression that the stones in an upper portion of the Illinoian till are fewer, smaller, and more resistant than those of a middle and lower portion, and that the difference is largely original. In the field-notes the two portions are referred to as the non-gravelly and the gravelly till. Further field-work in southern Illinois covering a part of each year since that time and laboratory tests have confirmed the impression, and brief examinations of the Kansan till in northern Missouri and other till sheets elsewhere lead to the inference that the feature is rather general. In some places the non-gravelly till has been erroneously identified as loess. The character of the few pebbles in the upper till indicates somewhat definitely that this till was never like the middle and lower portions of the deposit, though no doubt contemporaneous with them.

Read by title in the absence of the author.

PLEISTOCENE DEPOSITS BETWEEN MANILLA, IN CRAWFORD COUNTY, AND COON RAPIDS, IN CARROLL COUNTY, IOWA

BY GEORGE F. KAY

(*Abstract*)

Many deep cuts were made recently in connection with the improvement of the Chicago, Milwaukee and Saint Paul Railway between Manilla, in Crawford County, and Coon Rapids, in Carroll County—a distance of more than thirty miles. These cuts, some of which have a depth of more than 50 feet, furnish most interesting exposures of drift and related deposits, the study of which has enabled some phases of the Pleistocene history of Iowa to be interpreted somewhat more clearly than was possible previously.

The most significant features that have been revealed may be summarized as follows:

1. The chief kinds of material exposed are loess, Kansan gumbotil, Kansan drift, Nebraskan gumbotil, and Nebraskan drift. In no one cut is it possible to see all of these materials, nor are the two gumbotils exposed in a single cut. In some cuts the section shows loess, Kansan gumbotil, and Kansan drift; in other cuts there may be seen loess, Kansan drift, and Nebraskan gumbotil; in still others loess, Nebraskan gumbotil, and Nebraskan drift. The most comprehensive cut is about one and one-half miles west of Manning. It shows loess, Kansan drift, Nebraskan gumbotil, and Nebraskan drift.

2. The two drifts, the Nebraskan and the Kansan, are much alike lithologically, and both appear to have undergone similar changes. On each of the drifts gumbotil has been developed, below which there is a narrow zone of leached drift, which grades downward into unleached drift with many concretions.

3. The maximum thickness of Nebraskan gumbotil is about 13 feet and of the Kansan gumbotil more than 20 feet. The zone of oxidation of the Nebraskan drift is not fully exposed in any of the cuts; the greatest depth of oxidation seen was 17 feet. The zone of oxidation of the Kansan drift has a maximum thickness of about 40 feet. Beneath this oxidized zone, in a few cuts, there was seen less than 10 feet of very dark, tenacious, unleached, and unoxidized Kansan drift.

4. The Kansan gumbotil is limited in distribution to a few narrow divides which are erosion remnants of a former extensive Kansan gumbotil plain. These divides are the present uplands of the region. The Nebraskan gumbotil is exposed only in those cuts the summits of which have been brought by erosion considerably below the elevations of the summits of the upland cuts.

5. The loess is present as a mantle over the maturely dissected surfaces. It varies in thickness from a few feet to more than 25 feet. In general, it thickens from the crests of the ridges down the slopes, and is apparently thicker on east slopes than on west slopes. The upper parts of the ridges have been broadened more than heightened by the deposition of the loess. In places the loess lies on Kansan gumbotil; in places it is on Kansan drift; in other places it mantles the Nebraskan gumbotil; and where there has been the most extensive erosion previous to the deposition of the loess, it is on Nebraskan drift.

6. The loess has two phases, the upper of which is buff in color; the lower is gray. In many places the buff loess is leached for a few feet from the surface; in a few cuts the depth of leaching is about 15 feet. The buff and the gray phases of the loess are closely related, and the evidence indicates that their differences are the result of chemical reactions rather than of different epochs of deposition.

Presented in full extemporaneously.

Discussion

Mr. Frank Leverett inquired of Professor Kay whether he had found evidence that the gumbotil was originally different from typical boulder-clay. In reply to a question by Professor Rich, Mr. Leverett mentioned the wide lowlands bordering the lower courses of the Embarrass and Kaskaskian and other rivers in southern Illinois as examples of areas that are not undergoing stream trenching because they are too flat for streams to form such trenches.

In reply to Mr. Leverett, Professor Kay stated that the boulder-clay from which the gumbotil has been derived may have differed from typical boulder-clay, but he had no distinctive evidence in favor of this view. His impression was that in the case of the Iowan and Wisconsin drifts, which are too young to have had a gumbotil developed on them, the drift at and near the surface does not differ in any important respect from the drift which is deeper below the surface.

Dr. J. L. Rich: The speaker's interpretation of the relations of the two gumbotils to their underlying tills and his explanation of their origin involves a particular series of events twice repeated in identical order, namely, a long period of weathering under conditions precluding active stream erosion, followed by dissection, presumably resulting from diastrophism. It is difficult to believe that such a repetition of events is a purely accidental coincidence. If not, it seems to me that either the explanation is imperfect or there must be some causal relation between the periods of glaciation and of lagging diastrophism which would be of great significance if discovered.

In reply to Doctor Rich, Professor Kay stated that he recognized the full significance of the point raised, but he was unable to offer an explanation of the field evidence that would not involve the peculiar series of events that seem difficult to believe. But are not other series of events of the Pleistocene equally difficult to believe? What a succession of events is involved in the now generally accepted five glacial epochs and the four interglacial epochs!

Mr. J. E. Todd: 1. I would like to inquire how Doctor Kay harmonizes his statement of the close similarity of Nebraskan and Kansan tills with statements of earlier students of the subject that they were easily distinguishable by color and composition.

2. I would like to call attention to the occurrence near Aikins, Pottawatomie County, Kansas, of black boulders of supposed Nebraskan till in Kansas till. Furthermore, erosion is at an altitude considerably higher than central Iowa.

In reply to Professor Todd, Professor Kay stated that the earlier students of the drifts did not have opportunity to study the Nebraskan and Kansan drifts in all their relationships in widely distributed areas. Many important exposures have been made available for study only during the past few years

in connection with railway construction and the improvement of the roads of the State. It is quite true that in some parts of Iowa the Kansan drift can be distinguished readily from the Nebraskan drift within the same area; on the other hand, there are other places in Iowa where the color, composition, and other characters of the Kansan drift are so similar to the characters of the Nebraskan drift that it is impossible to distinguish the two drifts by such criteria.

LOESS-DEPOSITING WINDS IN THE LOUISIANA REGION

BY F. V. EMERSON[1]

(*Abstract*)

The eolian origin of the southern loess is generally conceded by most workers who have studied the formation within the last twenty years. It has long been recognized that strong westerly winds have deposited the wide loess belt along the eastern side of the Mississippi and the less frequent and persistent easterly winds have deposited the narrower, less continuous belt on the western side. The soils of the west belt contain considerably more potash than those of the east belt. The explanation offered is that the finer loess particles were carried to the west belt by the weaker easterly winds. Microscopic examination of Louisiana loess shows that the potash occurs in bits of orthoclase between 1/100 and 5/100 of a millimeter in diameter, and that practically all particles larger than this are quartz. It is therefore thought that the weaker easterly winds carried finer loads with a consequently higher percentage of orthoclase than the stronger westerly winds.

There are two "islands" of loess nearly or quite surrounded by Mississippi alluvium, and in each case the loess at the southern ends of these areas is thicker than at the northern ends. This seems to indicate that southerly winds (probably southwesterly and southeasterly) were important loess carriers in this region.

Read in full from manuscript.

STREAM MEANDERS

BY E. B. BRANSON

(*Abstract*)

Meanders are variously interpreted in recent text-books and articles. One text states that meanders begin to develop after a stream has cut to baselevel, while another states that they start in the early youth of a stream. This article discusses the development of meanders in young valleys.

Read by title, at the request of the author.

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[1] Introduced by A. P. Brigham.

NOTES ON THE SEPARATION OF SALT FROM SALINE WATER AND MUD

BY E. M. KINDLE

(Abstract)

The paper described a series of experiments showing (1) the facility with which salt escapes from vessels holding saline aqueous solutions during the evaporation of the water; (2) the influence of temperature in controlling the size of salt crystals; (3) the contrast in texture exhibited by fine-grained sediments formed in saline and fresh waters; (4) the different types of mud-crack developed in saline and non-saline calcareous mud.

The geological significance of some of the facts illustrated by the experiments was brought out by a discussion of the phenomena observed on the salt plains in the Northwest Territory. The bearing of the experiments on the theories relating to the origin of salt lakes and salt domes was also considered. Mud-cracks in limestone were described, which correspond in certain peculiar features to the two types developed experimentally in calcareous sediments.

Read in full from manuscript, by Dr. M. E. Wilson, in the absence of the author.

ADDITIONAL NOTE ON MONKS MOUND

BY A. R. CROOK

(Abstract)

Monks Mound, which lies about six miles east of the place of the 1917-1918 Geological Society of America meeting, in scholarly as well as in popular literature, has quite generally been described as of human origin.[1] As pointed out in former papers before the Geological Society of America,[2] inquiry along lithological and physiographical lines makes evident that this and the 70 other mounds in the region are but remnants of the glacial materials which formerly filled the valley. Since presenting that paper opportunity of making further investigation has been afforded. The samples of earth constituting the mound secured for the former studies were obtained by sinking 25 holes with a post-hole digger in the north or most abrupt face of the ground. Recently additional samples were secured by sinking a hole with an earth augur from the top down 25 feet and on the east side for 15 feet farther. Earth from the tops and sides of several other mounds was taken and all of these materials were compared. The result shows general similarity of materials in all the different mounds at similar levels and a change in the soil of Monks Mound when proceeding from the top to lower layers—a condition which would not be likely to exist if "Mound-builders" built these mounds, which are scattered over several square miles. It is reasonable to doubt that the so-called Mound-builders, or Indians, ever did build mounds of any considerable size. The burden of proof should rest with archeologists, who make the claims that elevations

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[1] See Transactions of the American Philosophical Society, Smithsonian Contributions to Knowledge, American Bureau of Ethnology, Encyclopedia Britannica, etcetera.

[2] Bull. Geol. Soc. Am., vol. 26, no. 1, 1915, p. 74, map.

which would appear to physiographers to be natural mounds were built by human hands.

Presented in full extemporaneously.

DISCUSSION

Mr. J. E. TODD: I would call attention in this connection to the fact that at the 1877 session of the American Association for the Advancement of Science, held in this city, a gentleman exhibited a model to show the similarity of the largest Cahokia mound to the pyramid structures of Mexico and Yucatan. At that meeting an excursion to the mounds was arranged. While on the trip I personally heard Doctor Worthen, State Geologist of Illinois, who had studied them, state his positive conviction that these mounds were not artificial but of natural origin.

Remarks were also made by Messrs. D. W. Ohern, I. C. White, and W. J. Sinclair.

SALIENT FEATURES OF THE GEOLOGY OF THE CASCADES OF OREGON, WITH SOME CORRELATIONS BETWEEN THE EAST COAST OF ASIA AND THE WEST COAST OF AMERICA

BY WARREN DU PRÉ SMITH

(*Abstract*)

The salient features of the stratigraphic succession in the Oregon Cascades, so far as known, are reviewed in this paper.

A survey of the literature and of the data gathered in recent field-work reveals the fact that not much is known with certainty about the formations and events prior to the Tertiary.

A second fact of importance, already known, is emphasized, namely, that the later geological history of California and Oregon is very much the same. This might appy to the State of Washington as well, but the writer has purposely omitted a discussion of this, since he has never done any work there.

The third fact of importance is the remarkable coincidences of geological events on opposite sides of the Pacific, which can not be fortuitous. The two most striking instances of these are the period of Tertiary gold deposition, practically contemporaneous around the entire Pacific arc, and the tremendous eruptions of basaltic and andesitic lavas which continue to this day, though not on so extensive a scale as in the past, and which have caused the regions bordering the Pacific to be designated as the "Circle of Fire."

The general conclusion is that the geology of the various countries bordering the Pacific must be deciphered and interpreted by duly considering the data from all these regions, and that, geologically at least, the Far East has much to contribute toward the solution of our Western problems and *vice versa*.

Read by title in the absence of the author.

CLINTON FORMATIONS IN THE ANTICOSTI SECTION

BY E. O. ULRICH

(*Abstract*)

Among the stratigraphic results of a monographic study of the Silurian Ostracoda is reasonably definite proof that the Gun River and Jupiter River formations of the Anticosti section are of Lower Clinton age. The upper part of the Gun River formation is shown to correspond to the Williamson shale in New York and to the basal 100 feet or so of the Clinton at Cumberland, Maryland, and at places in Pennsylvania. The same ostracod fauna is clearly recognized also in southwestern Virginia.

The Jupiter River ostracod fauna also is clearly indicated in the Clinton sections in New York and Maryland. Its zone in these States lies from 60 to 150 feet above that of the Gun River species, the variations in the thickness of the interval between them being dependent on the relative local completeness of the sequence of Clinton deposition and probably on local variations in rate of deposition and character of deposits.

Both of these faunal zones underlie the zone of *Mastigobolba lata* (*Beyrichia lata*—part, Hall), which lies near the middle of the Lower Clinton (Kirkland formation) in Pennsylvania and Maryland.

Read in full from manuscript.

Questions were asked and remarks made by Drs. I. C. White and John M. Clarke and the author.

The Society adjourned at about 6 p. m.

PRESIDENTIAL ADDRESS

At 8 o'clock p. m., at the Planters' Hotel, Prof. Frank D. Adams delivered his address as retiring President, his topic being

EXPERIMENT IN GEOLOGY

Published as pages 167-186 of this volume.

COMPLIMENTARY SMOKER

The address was followed by the complimentary smoker given by an association of citizens of Saint Louis in honor of the Geological Society of America and its friends.

Session of Friday, December 28

The Society convened at 9 o'clock a. m., with President Adams in the chair.

TITLES AND ABSTRACTS OF PAPERS PRESENTED AT THE MORNING SESSION AND DISCUSSIONS THEREON

STRAND AND UNDERTOW RECORDS OF UPPER DEVONIAN TIME AS INDICATIONS OF THE PREVAILING CLIMATE

BY JOHN M. CLARKE

(*Abstract*)

The effort to interpret the strand markings of the Portage sandstones in the light of records made on existing strands indicates that certain of these ancient strand marks are caused by the indirect action of ice, and that some of them may be due to ice crystallization. It is further indicated that such records of long continued cold are in accordance with other evidences of prevailing cold conditions during a part of the Middle and Upper Devonian period.

Read in full from notes.

Questions were asked by Dr. E. Blackwelder and Mr. F. Leverett and answered by the author.

REPORT OF THE AUDITING COMMITTEE

For the Auditing Committee, Eliot Blackwelder reported that it had examined the Acting Treasurer's accounts and had found them correctly cast and properly vouched; also that a member of the committee (Professor Reid) would later examine and report on the Society's securities, which are kept in its safe-deposit box at Baltimore.[1] On motion, the report was accepted and ordered placed on file.

The Society, on motion, took from the table and accepted the report of the Council as printed.

TELEGRAM TO DOCTOR WALCOTT AND REPLY

In view of the newspaper reports of the fall within the enemy lines of Dr. Charles D. Walcott's son, a member of the American Aviation Corps

[1] Report received by the Secretary: I have examined the securities of the Society and find that the list as printed in the report of the Council for 1917 corresponds to the securities held by the Treasurer.

(Signed) Harry Fielding Reid.

February 12, 1918.

in France, the Society instructed the Secretary to send a telegram of sympathy to its former President.[1]

ANNOUNCEMENT OF THE FIRE AT MOUNT HOLYOKE

The Secretary announced the receipt of a letter from Miss Mignon Talbot, Professor of Geology at Mount Holyoke College, relating to the total destruction by fire, on December 22, 1917, of Williston Hall, with all the scientific collections and apparatus of the college, and asking the help of the Fellows in building up again the collections in geology and paleontology.

The Society then proceeded to the consideration of scientific papers.

STUDY OF THE SEDIMENTS AS AN AID TO THE EARTH HISTORIAN

BY ELIOT BLACKWELDER

(*Abstract*)

Progress in the interpretation of the physical history of the earth depends in large measure on our understanding of the principles of correlation and the origin of the sedimentary rocks. Of the two, the study of the latter is the more urgent, because it will assist in unraveling the puzzles of the former.

At present our knowledge of the sedimentary rocks is very ragged. In order to fill out the deficiencies we need many detailed investigations of modern deposits and of the processes by which they are being made, and many equally minute studies of ancient sedimentary rocks. Important service may be rendered by geologists who are not specialists in sedimentation, if they will make their stratigraphic descriptions as accurate and definite as possible, give precise information regarding all chemical analyses of sedimentary rocks, and collect material with adequate field-notes from the less familiar regions of the earth, as they may visit them. Some of the problems will, of course, require expeditions and cooperative work beyond the power of the individual, but feasible for some of our scientific institutions.

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[1] In carrying out instructions, the following telegram was dispatched:

"Hon. CHARLES D. WALCOTT, Washington, D. C.:

"Geological Society of America, annual meeting assembled, extends heartfelt sympathy in your anxiety regarding son, who may have already made the greatest sacrifice possible for his country.

"EDMUND OTIS HOVEY, *Secretary*."

Doctor Walcott's Reply

"DEAR DOCTOR HOVEY: We greatly appreciate the thoughtfulness of the members of the Geological Society who assembled at Saint Louis in expressing their sympathy. The present situation is summed up in the following cablegram from General Pershing:

"'With reference to Stuart Walcott, his engagement took place in the Grand Bois de Saint Souplet region. His machine did not fall in flames and did not land so violently as to lose hope that he may be a prisoner.'

"Sincerely yours,

"(Signed) CHARLES D. WALCOTT."

A comprehensive understanding of the origin of the sediments will greatly facilitate the interpretation of the earth's climatic history and the evolution of the oceans; will give us far more accurate information regarding the distribution of land and sea and the topography of both, and will greatly strengthen our knowledge of volcanic epochs and diastrophic movements. We should even be able to understand those special and peculiar conditions which apparently are not now duplicated on the earth, but are implied by such deposits as the iron ores of eastern Brazil and the phosphate deposits of Idaho. An understanding of sedimentation is essential to the new and rapidly developing method of correlating rock formations, not simply on the basis of fossils or even diastrophism, but on the compound basis of life, climate, topography, vulcanism, and diastrophism, with critical regard to the relative values, mutual relations, and dependencies of all.

Read in full from manuscript.

Discussion

Dr. J. M. Clarke emphasized the new importance of closer study of the composition of sedimentary rocks along the lines suggested by the author and by the participants in the symposium on this theme held at the Albany meeting.

OPPORTUNITIES FOR GEOLOGICAL WORK IN THE FAR ARCTIC

BY W. ELMER EKBLAW [1]

(*Abstract*)

Great areas of Greenland and the Arctic Archipelago are nearly, or quite, unexplored by geologists. Ellesmere Land and Greenland offer the best opportunities for study of glaciers fed from great ice-fields, of the climatic conditions under which these ice-fields are formed, and of the resulting attendant phenomena.

The Arctic Archipelago presents such a diversity of physical conditions that it affords especially favorable opportunities for the comparison of physiographic phenomena characteristic of Arctic climates with those characteristic of other climates.

Because the land is practically free from vegetation, and during the summer months, when work is possible, most of the ground is bare of ice and snow, the numerous structural problems which are presented throughout the Arctic Archipelago are not so difficult of study as is generally supposed.

In only a few localities is the stratigraphy fairly well known. Only scattered observations have been made and collections of fossils are few and far between. This dearth of knowledge and material is due to neglect of the field rather than to paucity of exposures or fossils, for great tracts of sedimentaries are bare throughout the summer season and many beds are more or less fossiliferous.

There is no lack of opportunity for geologic work in the far Arctic; the want is men to do the work.

Read in full from manuscript.

[1] Introduced by W. S. Bayley.

Discussion

Dr. A. P. Coleman congratulated Mr. Ekblaw on showing how large a field for geological work still remains open in the Arctic islands. On the mainland, in Labrador, there is also much room for work. Two summers' work have shown a large area in northeastern Labrador that was not covered by the Pleistocene glaciers, as in some areas which he has mentioned in the far north.

Dr. E. O. Hovey: Mr. Ekblaw's trip across Grant Land and results obtained, including collections, testify to the value of the geological observations made in connection with the Crocker Land Expedition.

In his reply the author emphasized the desirability of establishing a scientific station in Labrador.

GENESIS OF MISSOURI LEAD AND ZINC DEPOSITS

BY W. A. TARR [1]

(*Abstract*)

A review is made of the current views that the lead and zinc deposits owe their origin to circulating ground waters which obtained the metals from the dolomites and limestones of the Ozark area or from once overlying, but now removed, beds.

There are serious objections to these views, among which are the amounts of the metals in the original rocks, their distribution in them, their relationship to the solution channels, and the character of the circulation of the ground waters and its quantitative possibilities. Results of recent studies in related subjects offer new evidence which favors the view that they were deposited by rising thermal solutions.

Read in full from manuscript.

Discussion

Dr. A. R. Crook: Has the author not underestimated the permeability of rocks, illustrated by the treatment of agate in commercial manufactures?

Dr. W. H. Emmons stated that he had proved the considerable permeability of some igneous rocks by soaking them in red ink. Does pyrrhotite occur as reported by Winslow?

The author replied that linnæite occurs and has been mistaken for pyrrhotite. Hydrothermal action has been noted. Permeability has been studied.

Dr. F. R. Van Horn: Doctor Tarr seems very certain that the Missouri zinc and lead deposits were derived from igneous rocks and brought to their present position by ascending waters. This non-argentiferous type of deposit is found in three different parts of Missouri, from the upper Mississippi Valley in Illinois, Wisconsin, and Iowa, from Belgium and western Germany, and from Silesia, Galicia, and Poland. At all of these places the ores are associated with dolomitic limestones of Cambrian, Ordovician, Mississippian, and Triassic age. Small amounts of sphalerite are found in the Niagara limestone in Ohio, and galena occurs in the Lockport dolomite in Ontario, these rocks being of

[1] Introduced by E. B. Branson.

Silurian age. Both minerals are found in the Keokuk, in southeastern Iowa, as geodes. Doubtless many are familiar with other occurrences which are not known to me. The presence of zinc and lead from so many localities and different geological horizons can be no accident. From all the above places igneous rocks seem to be absent. It seems as if the metals must have been derived from associated or previously overlying eroded limestones. In my opinion, it is not necessary that the metals should have been originally precipitated in sulphide form, but as carbonates. The metals found commonly in such ore deposits are Ca, Ng, Fe, Zn, Mn, Ba, Sr, Pb, and Cu. All but the last occur in the isomorphous calcite and aragonite groups. Meigen has shown that various invertebrates secrete both calcite and aragonite shells or skeletons. When the animal forms a shell of calcite it should also take up a certain amount of Mg, Fe, Mn, and Zn. If it secretes an aragonite shell it is likewise to be expected that it will absorb some Sr, Ba, or Pb. Van Ingen and Phillips have recently shown that the bodies of gastropods, crustaceans, and echinoderms also constantly contain Cn, Fe, Zn, and Mn, with Pb occasionally. This is additional evidence that limestones must contain disseminated metals. I have nothing to say as to how this type of ore deposits reached their present position. Of course, the lateral secretion theory of Sandberger or precipitation by descending waters have prevailed; but I have no objection to Doctor Tarr's theory of ascending waters, and I certainly feel that we have good reasons for considering the limestones as the direct source of the metals, although I also feel that the metals originally came into sea-waters by the decomposition of minerals from igneous rocks.

Mr. H. A. Wheeler: The permeability of compact limestone is well illustrated in a bed of very compact, close-grained lithographic limestone that occurs in a quarry on Barton and First streets, in south Saint Louis, in the upper portion of the Saint Louis limestone. Blocks of this seemingly impervious rock that show no seams to the eye are found to contain vugs or cavities one to six inches in size when broken open. These vugs are lined with curved rhombic pink crystals of dolomite, through which project beautiful complex crystals of prismatic calcite, and the remaining space is more or less completely filled with millerite, or sulphide of nickel, in a filiform or hairlike form. Occasional small crystals of gypsum, galnite, and sphalerite also incrust the calcite crystals. The Emistein mine, 10 miles west of Frederickstown, Missouri, alluded to by Professor Tarr, is the largest and strongest fissure vein thus far found in the granitic area of southeast Missouri, but smaller, nonprofitable, quartz veins in the granite and porphyry are quite frequently found that usually carry more or less argentiferous galena or copper sulphides. The silver content is usually not large, 5 to 25 ounces per ton, and the veins are apt to be only a few inches in width, with a quartz filling.

RELATION BETWEEN OCCURRENCE AND QUALITY OF PETROLEUM AND BROAD AREAS OF UPLIFT AND FOLDING

BY EUGENE WESLEY SHAW

(*Abstract*)

In attempting to find the cause of the fact that most of the oil and gas occurs in geosynclines, and that there seems to be some relation between the

character of the hydrocarbons and general structural features, attention should be given to the following considerations, in addition to the geographic arrangement: (1) The fact that the strata are higher and the rocks more fractured in the regions of uplift; (2) the possibility that the present areas of geanticlines were areas of uplift and the geosynclines areas of depression at the time the strata were laid down, and that for this, and perhaps other reasons, conditions and original deposits were different; (3) other respects in which the history and conditions likely to have affected the formation, retention, and character of oil have been different; (4) the question of whether or not oil and gas pools were formed in the geanticlines, and if they were, what was their history and why are few, if any, traces left; (5) the extreme improbability of thrust pressures affecting the fluids in rock pores to an extent greater than 50 or 100 per cent above the hydrostatic head, for higher pressures would presumably squeeze out the fluids, and differences in superincumbent load seems to have little effect on the quality of petroleum; (6) the great and apparently irregular quality variations of the hydrocarbons in short distances—the innumerable and extensive departures from harmony among the data; (7) the greater abundance of salt water in the geosynclines, indicating poorer circulation; (8) the effects of filtration during migration of the oil; (9) the quality of the relict portion of the parent material, particularly in any central portions of the compressed areas where the pressure may have been locally relieved; (10) the principles of physical chemistry that are concerned, particularly the possibility of pressure affecting the chemical transformations; (11) the chemical reactions that may have been induced by substances other than carbon and hydrogen and their compounds, such as sulphur, chlorine, and clay.

It seems to the writer (1) that more than one hypothesis is in accord with most of the available facts and established principles; (2) that, contrary to certain statements, no hypothesis thus far offered fits all the evidence; (3) that probably there are several reasons why oil and gas occur mainly in geosynclines and more than one reason for the apparent relation between quality and distance from centers of uplift; (4) that a basinward or down-dip migration has been general and has been at least a partial cause of quality relationships, the gas perhaps tending to lag behind in the downward movement because of its extreme lightness, and possibly certain oils because of their great viscosity.

Read by title in the absence of the author.

NEW POINTS IN ORDOVICIAN AND SILURIAN PALEOGEOGRAPHY

BY T. E. SAVAGE AND FRANCIS M. VAN TUYL

(*Abstract*)

As a result of a study of the early Paleozoic formations of the Hudson Bay region and of Wyoming, new data bearing on the paleogeography of Ordovician and Silurian time have been obtained.

Presented by the senior author in abstract from notes.

DATING OF PENEPLAINS: AN OLD EROSION SURFACE IN IDAHO, MONTANA, AND WASHINGTON—IS IT EOCENE?

BY JOHN L. RICH

(*Abstract*)

The correct dating of wide-spread erosion surfaces, or peneplains, is a matter of the greatest importance because of their value as datum planes for the interpretation of recent earth history.

A consideration of the probable fate in store for the elaborate superstructure reared on the determination of the origin and dating of the so-called Cretaceous peneplain of eastern United States, which seems about to crumble as a result of the recent work of Barrell and Shaw, should cause physiographers and geologists to pause and weigh well the evidence before accepting the fact or the dating of similar erosion surfaces elsewhere.

An old erosion surface, or peneplain, which seems to have wide development in Idaho, Montana, and Washington, has been definitely dated as Eocene by Umpleby and Atwood. Inasmuch as this dating has been questioned, a detailed examination of the published evidence has been undertaken.

The correctness of the determination of the Eocene age of the erosion surface hinges mainly on whether certain broad, intramontane troughs, in which lie Oligocene and Miocene sediments, were developed before or, as maintained by Umpleby and Atwood, after the peneplain was cut. Examination of the published evidence fails to reveal any convincing proof that the basins are younger than the peneplain. On the contrary, it brings out many features of the geology and physiography of the region which do not harmonize with this explanation.

Oligocene and Miocene sediments in the basins are commonly highly deformed; the contacts of the sediments with the basin walls, in some places at least, are faults; the basin floors are far from being parts of a graded system, and to restore the graded condition by uplifting, dropping, or tilting faulted blocks would throw the peneplain remnants far out of harmony; and, finally, the broad basins are physiographically entirely out of accord with the valleys of the present drainage systems, which are prevailingly narrow, V-shaped canyons, whose derivation in a single cycle from the former system by a process of headward erosion or stream piracy, as has been suggested by Umbleby and Atwood, is a physiographic impossibility.

Far from proving an Eocene age for the peneplain, the field relations described by the authors of that dating seem to prove that the basins in which the Miocene sediments lie were blocked out, filled, and suffered most of their deformation before the peneplain was cut.

Read in full from manuscript.

Discussion

Dr. Bruce L. Clark: Recent vertebrate collections made by Prof. J. C. Merriam in the so-called lake beds of Doctor Umpleby are much later in age than Umpleby supposed, being, if I remember correctly, Upper Miocene or Lower Pliocene in age.

Dr. ELIOT BLACKWELDER: Adverse criticism of our colleagues is always disagreeable, but in such a case as this it becomes a duty. It seems to me that Doctor Rich has done us a service in analyzing the arguments relating to the alleged Eocene peneplain of the Northwest. I have followed this matter for several years and have been to some extent involved in the controversy. In my opinion, Doctor Rich is correct in his conclusions.

Remarks were also made by Dr. L. G. Westgate.

IRON FORMATION ON BELCHER ISLANDS, HUDSON BAY, WITH SPECIAL REFERENCE TO ITS ORIGIN AND ITS ASSOCIATED ALGAL LIMESTONES

BY E. S. MOORE

(*Abstract*)

The Belchers are a group of large islands, nearly 100 miles in length, lying about 70 miles northwestward from the mouth of Great Whale River, Hudson Bay. They were little known until three years ago, when large areas of jaspilite were discovered on their shores. The sedimentary series, with the associated igneous intrusions and extrusions, is related to the group on the east coast of Hudson Bay and bears a close resemblance to the Animikie and Keweenawan rocks of the Lake Superior region. They show, however, a remarkable development of algal structures, which indicates either that these rocks are younger than the Precambrian or that an abundance of life of low type existed in the Hudson Bay basin during Precambrian time. Since the iron formation contains outlines of weathered globular granules, it seems probable that the algæ may have had a part in precipitating iron carbonate and silica in concretionary form.

Read by title in the absence of the author.

The Society adjourned soon after noon and reconvened at 2.30 p. m., with Dr. J. M. Clarke in the chair.

The Society proceeded immediately to the consideration of scientific papers.

TITLES AND ABSTRACTS OF PAPERS PRESENTED BEFORE THE AFTERNOON SESSION OF FRIDAY

SUBPROVINCIAL LIMITATIONS OF PRECAMBRIAN NOMENCLATURE IN THE SAINT LAWRENCE BASIN

BY M. E. WILSON

(*Abstract*)

The detailed geological work carried on in recent years throughout the southern part of the Canadian Precambrian shield has shown that the geological succession in the ancient terranes of this territory is regionally less uniform and includes a greater number of rock series than was formerly sup-

posed. Moreover, it has become evident that the wide-spread correlations implied by the use of the same nomenclature nearly everywhere throughout this great Precambrian province assumes much more with regard to the regional succession in these ancient rocks than is actually known.

Although it is not possible generally to demonstrate, with mathematical conclusiveness, that geological formations occurring in different localities are equivalent, nevertheless the premature use of the same name for formations the correlation of which is open to question, or the continued use of the same name for formations after it has become evident that their correlation is in doubt, is misleading, and an obstacle rather than an aid in geological investigation. Hypothetical correlations of groups of rocks occurring in widely separated districts may serve for comparison or as a stimulus to investigation, but all the advantages of such tentative correlations may be attained by using a general terminology (Proterozoic, Archæozoic, etcetera), and thereby avoiding the definite correlations implied in the use of names of local origin. In the Precambrian province which occupies the northern part of the Saint Lawrence River basin there are four geographically and geologically separate subprovinces: (1) The region northwest of Lake Superior, (2) the region south of Lake Superior, (3) the region extending northeastward from Lake Superior and Lake Huron to Lake Timiskaming and Lake Mistassini, and (4) eastern Ontario and the lower Saint Lawrence, with which might be included the Adirondack region. With the possible exception of the south shore of Lake Superior and the Lake Huron and Lake Timiskaming subprovinces, the evidence on which the rocks of these separate regions can be correlated is exceedingly meager, and for the present, at least, the only logical course would seem to be to build up a separate nomenclature in these various subprovinces by using those names already defined in these localities, supplemented by such local new names as becomes necessary from time to time as geological investigation is continued.

The wide-spread correlations implied in the use of a common nomenclature throughout all the Precambrian subprovince of the Saint Lawrence basin has been based on the assumption that the succession of formations within the various subprovinces has been worked out to a practical completeness and on the application of certain principles by which the correlation of the various formations in these widely separated areas are presumed to be established. The writer's purpose is to point out that the assumption that our knowledge of the succession of formations in any of the subprovinces is complete is open to question, and that the principles by which Precambrian rocks are generally correlated are in part inapplicable and as a whole quite inadequate for the establishment of a Precambrian nomenclature embracing all the territory in the Saint Lawrence basin in which Precambrian rocks occur.

Read in abstract from manuscript.

Discussion

Dr. A. P. Coleman: Doctor Wilson's paper is of importance as showing the danger of extending a classification of the Precambrian worked out in one region to other widely separated regions. His suggestion of more than two ages of batholithic mountain-building lengthens out still farther the tremen-

dously long Precambrian history of the world, which probably much exceeds in length the latter parts of the world's history. He seems a little too pessimistic, however, in regard to the working out of a general classification of the Precambrian. The close parallelism of the succession found in different regions seems to suggest a real basis for classification.

Dr. W. J. Miller: Doctor Wilson has sounded a note of comfort to some of us at least who work with Precambrian rocks. For one, I have not been able to keep pace with the ideas definitely expressed in several recent correlation tables. In the Adirondack region I have even hesitated to use the old term "Laurentian" because there is so much difference regarding its use. I agree with Doctor Wilson when he maintains that definite correlations covering the region from western Ontario to the Saint Lawrence Valley are out of order until many more field facts are well in hand.

FURTHER STUDIES IN THE NEW YORK SILURIC

BY GEORGE H. CHADWICK

(*Abstract*)

The analysis and correlation of the Cayugan "waterlimes" has been carried eastward to Cayuga Lake in the effort to show the true position of the so-called Cobleskill and Rondout, in the western sections. Studies also made of the New York Clinton sections have suggested the necessity for some readjustments in the present classification.

Read by title in the absence of the author.

RELATION OF THE OIL-BEARING TO THE OIL-PRODUCING FORMATIONS IN THE PALEOZOIC OF NORTH AMERICA

BY AMADEUS W. GRABAU

(*Abstract*)

The oil-bearing formations which will be considered are: The Trenton limestone, the Onondaga (Corniferous) limestone, the Upper Devonic sands of southwestern New York and northwestern Pennsylvania, and the Berea sandstone. The widely held view that the oil of the Trenton and Onondaga limestones was produced from the soft part of the animals which secreted the calcareous structures from which these limestones are formed is untenable, since the conditions of accumulation of zoogenic and phytogenic limestones in the sea involves the destruction of the organic matter by contemporaneous scavengers. Even where the limestones are wholly composed of shells and corals, these are practically pure lime accumulations, free from organic material. That the oil of the Upper Devonic and of the Berea sandstone could be derived from the organisms contained from the inclosing beds need hardly be seriously considered.

In the case of the oil-bearing formations mentioned, and probably in the majority of oil-bearing formations of all horizons, the source of the oil is to be sought in the black shales, either sapropelitic or humulitic, which occupy corresponding horizons in an adjoining area and from which the oil (and gas)

passes laterally into the porous strata which bear them. This implies, of course, that the respective formations must be in replacing relationship, either that of replacing overlap or an interfingering relation. The Utica shale, in the larger sense, has a replacing overlap relation to the Trenton limestone and is the source of the oil of that rock. In the east the Trenton horizon is black shale, rich in carbonaceous matter. Westward it passes laterally into Trenton limestone, though at any one locality Lower Trenton limestone is overlain by higher "Utica" shale. Each division of the black shale, however, passes westward into limestone, and the passage of the oil was from the shale where it originated along the bedding planes into the limestones, where it was stored. The Marcellus shale has the same relation to the Onondaga limestone and is the source of the oil of that formation. The Portage and Chemung sands of the Bradford region apparently derive their oil from the black shales, which replace them westward and which in Ohio form the black Ohio shale, which, as I have elsewhere shown, is a stratigraphic equivalent. The Berea oil appears to be derived from a part of the Chattanooga black shale, which replaces it to the southward. This relationship, too, I have elsewhere demonstrated.

Read by title in the absence of the author.

REVISION OF THE MISSISSIPPIAN FORMATIONS OF THE UPPER MISSISSIPPI VALLEY

BY STUART WELLER AND FRANCIS M. VAN TUYL

(*Abstract*)

In accordance with the cooperative plan of study and correlation of the Mississippian formations of the Mississippi Valley, furthered by the several State Geological Surveys of the region, the writers have been occupied with the investigation of these deposits in Iowa and western Illinois since 1913. As a result of these studies, more complete data bearing on the composition of the faunas of the more important horizons has been obtained and a revision of the boundaries of certain formations has been necessitated.

Read by title in the absence of the author.

NOTES ON THE STRATIGRAPHY AND FAUNAS OF THE LOWER KINDERHOOKIAN IN MISSOURI

BY E. B. BRANSON

(*Abstract*)

A thin sandstone, which rests unconformably on various older formations, is the usual basal Kinderhookian, but in some places shales come in below the sandstone. The sandstone seems to correspond to the Sylamore of Arkansas. Fish remains are of common occurrence in the sandstone, while marine invertebrates have been found in only one locality.

Presented in full extemporaneously.

Remarks were made by Dr. E. O. Ulrich, with reply by the author.

MEGANOS GROUP, A NEWLY RECOGNIZED DIVISION IN THE EOCENE OF CALIFORNIA

BY BRUCE L. CLARK [1]

(*Abstract*)

An unconformity believed to be of more than local importance is recognized in the Eocene deposits of Mount Diablo, California, in a section heretofore recognized as representing the Tejon group of the Upper Eocene. This unconformity is indicated by difference in strike and dip, together with other evidences of erosion. The beds above the contact contain a typical Tejon fauna, while those immediately below contain a faunal representation differing considerably from that of the typical Tejon, and also differing from the typical Martinez fauna of the Lower Eocene. Strata representing the Martinez are found in this section unconformably below the newly recognized Stewartsville group.

The name Meganos is given to the new group situated between typical Martinez and typical Tejon. It is believed that deposits of the Meganos group have a wide distribution throughout the coast ranges of California. In certain localities they have been referred to the Martinez group and at other places to the Tejon.

Presented in full extemporaneously.

Remarks were made by Dr. Eliot Blackwelder.

AGE OF THE MARTINSBURG SHALE AS INTERPRETED FROM ITS STRUCTURAL AND STRATIGRAPHICAL RELATIONS IN EASTERN PENNSYLVANIA

BY F. F. HINTZE

(*Abstract*)

Isolated masses of Martinsburg shale occur several miles to the east of the main body of shale and slate rock, lying unconformably on older rocks, from the Hardyston (Lower Cambrian) to the Trenton. The Martinsburg has been correlated with the "Hudson River" shale, and its age variously determined to be Trenton or Utica on the basis of graptolite remains found at localities in Pennsylvania, New Jersey, and New York. The decided unconformity of the Martinsburg on the older Cambrian and Ordovician beds shows a period of folding and considerable erosion prior to the end of Martinsburg time, before the beds of which the isolated masses or remnants were deposited. Fossils have not been found in these detached areas of Martinsburg shale, the identification of the material as Martinsburg being based on lithologic characters which bear a very striking resemblance to those of the main body of the shale.

In New Jersey the Martinsburg has been described as following the Jacksonburg limestone (Lowville, Black River, and Trenton) in normal conformable sequence, and on the basis of graptolites found the lower part of the Martinsburg is here correlated with the middle part of the typical Trenton of

[1] Introduced by John C. Merriam.

New York. As no break occurs at the base of the Martinsburg, the interval of folding and erosion indicated by the unconformity above mentioned came later, the exact time being unknown at present. After the erosion interval followed more shale deposition, the new deposit overlapping the Lower Martinsburg and all the older formations that had been truncated by erosion.

The upper part of the Martinsburg is thus distinctly younger than the lower part and may belong to the late Ordovician, possibly Richmond, and the break may correspond in time with that found in the Mississippi Valley between the Galena (Trenton) limestone and the Maquoketa (Richmond) shale.

Read by title in the absence of the author.

INVERTEBRATE FAUNA OF THE GRASSY CREEK SHALE OF MISSOURI

BY DARLING K. GREGER[1]

(*Abstract*)

In a paper on the formations in the vicinity of the Cap au Gres fault, published by Keyes, in the Transactions of the Iowa Academy of Science, 1897, page 12, the Grassy Creek shale is described in the following manner: "Immediately beneath the well defined Louisiana limestone, in the vicinity of the town of Louisiana, there are about six feet of black and green shales carrying a characteristically Devonian fish fauna. Ten miles west, on Grassy Creek, these shales attain a thickness of 30 feet, but southward they thin out completely before the limits of Pike County are reached."

North of the region of the type locality outcrops of the formation are found in Ralls and Marion counties and the maximum thickness is probably far in excess of the figure given by Keyes.

The vertebrate fauna has been described by Branson, in a bulletin of the University of Missouri, and the invertebrate species of the association are described in the present paper. The fauna, as I have elaborated it, is one quite characteristic of the type of sediment, consisting in the main of inarticulate brachiopods. Without attempting to draw any definite deductions as to the age of the formation from the evidence offered by the fauna, as I have worked it out, I give the following list of species:

Ptychostylus subtumidus Gurley.
Lingula missouriensis Rowley.
Lingula pikensis sp. nov.
Lingula tantilla sp. nov.
Lingula rowleyiana sp. nov.
Lingula insolata sp. nov.
Lingula yatsui sp. nov.
Lingula conklini sp. nov.
Athyris bransoni sp. nov.
Adolfia cf. *amarus* Swallow.
Douvillina cf. *mucronata* Conrad.
Palæonilo compressa sp. nov.
Pterochænia longwelli sp. nov.

Read by title in the absence of the author.

[1] Introduced by E. B. Branson.

SOME DEFINITE CORRELATIONS OF WEST VIRGINIA COAL BEDS IN MINGO COUNTY, WEST VIRGINIA, WITH THOSE OF LETCHER COUNTY, SOUTHEASTERN KENTUCKY

BY I. C. WHITE

(*Abstract*)

The new Volume IV, Part L, Series IV, of the Kentucky Geological Survey, J. B. Hoeing, State Geologist, gives much valuable detailed information on the Kanawha Series of Coals, so extensively mined at Jenkins, McRoberts, Fleming, and other points in Letcher County, Kentucky. This publication, by A. F. Krider, gives for the first time such accurate and detailed descriptions of the stratigraphic column of the southeastern Kentucky and adjoining Virginia region coal fields that it now becomes possible to correlate several of these Kentucky and Virginia coals definitely with the main beds of the Kanawha Series as studied and classified by White, Hennen, and Reger in Mingo and adjacent counties of West Virginia.

Presented in full extemporaneously.

RECORDS OF THREE VERY DEEP WELLS DRILLED IN THE APPALACHIAN OIL FIELDS OF PENNSYLVANIA AND WEST VIRGINIA

BY I. C. WHITE

(*Abstract*)

The detailed records of three deep wells are given in this paper: (1) Derrick City, near Bradford, Pennsylvania; (2) Geary well, near McDonald, Pennsylvania, and (3) the Martha Goff well, near Clarksburg, West Virginia, the latter two of which exceed 7,000 feet in depth. In addition to the interesting stratigraphic data afforded by the records, reference is made to the temperature results obtained by Mr. C. E. Van Orstrand, Physical Geologist of the United States Geological Survey, through the courtesy of Messrs. Pew and Corrin, vice-presidents of the Hope Natural Gas Company, who expect to make the Goff well the deepest one ever drilled, and thus exceed that of the famous one at Czuchow, which stopped at 7,349 feet.

Presented in full extemporaneously.

DISCUSSION

Mr. DECKER: With reference to the distribution of the salt mentioned by Doctor White, no salt, but about 150 feet of gypsum and interstratified shales, occur in the deep well at Erie, Pennsylvania. However, in a deep well on the farm of Mr. Hindekoper, west of Conneaut Lake, Pennsylvania, a thickness of 75 feet of salt has been reported.

Dr. F. R. VAN HORN: In the Cleveland, Ohio, district we have five Salina salt strata aggregating something like 160 feet instead of 100 feet, as stated by Doctor White. He has indicated that in the records of these deep wells no gas was found in what he calls the Niagara limestone. In Cleveland, in what we think to be the Lockport dolomite, we have the horizon called the Newburg

sand, in which was found the famous Staddler well, which started our gas boom. This well had an initial flow of over 12 million cubic feet daily. This horizon was found about 2,400 feet below the surface. Three hundred feet below this is the so-called Clinton sand, which has been the source of most of our gas. I may also state, in the absence of Cushing and Ulrich, that for over three years they have considered the Clinton sand as Medina age, thus agreeing with the conclusions just expressed by Doctor White.

Remarks were also made by Professors A. P. Coleman and J. F. Kemp, and reply was made by the author.

TENTATIVE CORRELATION OF THE PENNSYLVANIA STRATA IN THE EASTERN INTERIOR, WESTERN INTERIOR, AND APPALACHIAN REGIONS BY THEIR MARINE FAUNAS

BY T. E. SAVAGE

(Abstract)

In this paper the faunas of the successive marine fossil-bearing horizons in the western interior, eastern interior, and Appalachian regions are compared. A study of the vertical range of the species of Pennsylvanian fossils in these regions has shown that certain species have such limited vertical range that it is thought they can be used as trustworthy markers of different horizons in the respective basins, and that these furnish more accurate means of correlation than any criteria that have hitherto been available.

These studies indicate that the arch that at present separates the eastern interior and western interior coal basins along the Mississippi River was developed at the close of the Mississippian period, before the earliest Pennsylvanian sediments were laid down, and that it effectively separated the seas that occupied a large part of Illinois and Missouri during Pennsylvanian time, although toward the north these seas may have been temporarily united during a small part of the Pottsville epoch.

Read in full from manuscript.

Remarks were made by Dr. J. M. Clarke.

PRECAMBRIAN ROCKS IN THE MEDICINE BOW MOUNTAINS OF WYOMING

BY ELIOT BLACKWELDER AND H. F. CROOKS

(Abstract)

The Medicine Bow Range, west of Laramie, Wyoming, hitherto neglected by geologists, contains one of the most varied sections of Precambrian rocks in western United States. In addition to the usual gneissic and schistose complex, more than 25,000 feet of slightly metamorphosed sedimentary rocks, such as quartzites, slates, dolomites, lava flows, pyroclastics, and tillites, are exposed without repetition. Although but little of the detailed study of the rocks has yet been carried out, a preliminary outline can be given, and the empirical sequence will be briefly discussed. The correct interpretation of the stratigraphy depends on an accurate knowledge of the structure, and that remains in doubt. In this interesting case it has been found that the testimony of the primary sedimentary structures is generally opposed to the apparent implica-

tion of the secondary or deformative structures. The problem thus raised will be considered and solutions offered.

Read in full from manuscript.

GEOLOGIC MAP OF BRAZIL

BY JOHN CASPER BRANNER

(Abstract)

The text to accompany the new and comprehensive geological map of Brazil, which has been offered to the Society for publication, was presented.

Read by title in the absence of the author.

NOTES ON THE GEOLOGY OF THE REGION OF PARKER SNOW BAY, GREENLAND

BY EDMUND OTIS HOVEY

(Abstract)

Parker Snow Bay indents the coast about midway between Cape York and Cape Athal. The southern shore and the outer portion of the northern side consist of strongly hornblendic gneisses containing intrusive masses of basic igneous rock. The eastern portion of the northern side is feldspathic gneiss, apparently younger, which contains heavy dikes of basaltic character. The gneisses are generally considered to be Archean in age. Over the feldspathic gneiss, in the northeastern quarter of area, begins the series of Huronian (?) quartzites, quartz schists, etcetera, which appear to be well exposed along the coast to a point beyond Etah. Solifluction, terracing, and glaciation were noted. Evidence of comparatively recent elevation was observed.

Presented in abstract extemporaneously.

Society adjourned at about 5.30 o'clock p. m.

ANNUAL DINNER

The annual dinner of the Society and its friends was held at 7.30 o'clock, at the Planters' Hotel, Fourth and Pine streets.

Under the chairmanship of President Frank D. Adams, in response to the chairman's call, speeches were made by Messrs. J. M. Clarke, A. P. Coleman, P. N. Moore, James F. Kemp, Eliot Blackwelder, and E. B. Branson. Seventy-five Fellows and guests were present.

Session of Saturday, December 29

The Society convened at 9 o'clock a. m., with President Adams in the chair, and proceeded to the consideration of scientific papers.

TITLES AND ABSTRACTS OF PAPERS READ BEFORE THE SATURDAY MORNING SESSION

FIELD RELATIONS OF LITCHFIELDITE AND SODA-SYENITE OF LITCHFIELD, MAINE

BY REGINALD A. DALY

(*Abstract*)

The original type of nephelite syenite, litchfieldite, hitherto known only in the form of glacial erratics, has been discovered in a place near South Litchfield, Maine. The rock occurs as small lenticular injections, roughly parallel to the vertical schistosity and bedding of the inclosing sediments. Nephelite-free, soda-rich syenites constitute associated injections of similar form and relations.

Read by title in the absence of the author.

ADIRONDACK ANORTHOSITE

BY WILLIAM J. MILLER

(*Abstract*)

This paper dealt with the whole problem of the structure and origin of anorthosite, with special reference to the Adirondack region. Particular attention was given to Bowen's recent paper in the Journal of Geology, in which he elaborates an hypothesis to account for the structure and origin of the Adirondack anorthosite. As a result of six months of detailed field-work within and close to the great anorthosite area of northern New York, the present writer finds Bowen's hypothesis untenable.

Further evidence in support of Professor Cushing's contention that the anorthosite is a separate intrusive body distinctly older than the syenite-granite series was presented, but many new points which have important bearings on the whole problem were considered.

Among the principal topics discussed were the following: Variability of the anorthosite and its significance; the chilled border facies and its significance; relation of the anorthosite to the Grenville series; relation of the syenite-granite series to the anorthosite; anorthosite and syenite-granite mixed rocks; general absence of syenite and granite from the anorthosite area, and probable origin of the anorthosite by differentiation on a laccolith of gabbroid magma.

Read in abstract from manuscript.

DISCUSSION

Dr. W. S. BAYLEY congratulated Professor Miller on his attempt to study the anorthosites in the field rather than in the laboratory. He corroborated the speaker's observation that the anorthosites are not pure feldspar rocks. In Minnesota the anorthosite passes by uniform gradations into olivine gabbro, all phases of the gradations being recognizable.

In the highlands of New Jersey—an area in which the geology is very similar to that of the Adirondacks—the quantity of syenite gneiss is so great

that it is difficult to imagine these rocks to be acid differentiates of a gabbroitic magma, since gabbros are present only in insignificant patches in the district. Moreover, the syenites are not at all like the granophyric rocks associated with gabbros in Minnesota and at Sudbury.

Dr. F. F. Grout: It may be well to record two points in which the Duluth gabbro and related sills are less favorable to Doctor Bowen's idea of anorthosite formation than he thinks. At Duluth gabbro was intruded at two periods. The first and smaller mass seems to contain about 85 per cent plagioclase. It has large volumes of anorthosite differentiate. The second intrusion has more nearly 70 per cent plagioclase, but has numerous layers of anorthosite of smaller size. Since magmas vary from 70 to 85 per cent in plagioclase, as intruded, it seems certain that some may be intruded with over 90 per cent plagioclase when they would be classed as anorthosite. Bowen, in outlining the origin of anorthosites, refers to Winchell's observation that some diabases have lumps of anorthosite and scattered crystals of plagioclase. I have seen the lumps described, and have seen lumps apparently identical in nature and relation in the "red rock," from which they could not have formed by segregation. I have no hesitation in stating that these lumps of anorthosite are xenoliths, not segregations.

Remarks were also made by Professors James F. Kemp and Frank D. Adams.

PETROLOGY OF RUTILE-BEARING ROCKS

BY THOMAS LEONARD WATSON

(*Abstract*)

The paper presents a discussion based on chemical and microscopic studies of the petrology of rutile-bearing igneous rocks in general, including the more important districts in this country and abroad.

Read by title in the absence of the author.

INTERNAL STRUCTURES OF IGNEOUS ROCKS

BY FRANK F. GROUT [1]

(*Abstract*)

The igneous rock structure emphasized is an alternation of bands of varying mineral composition. In many places this is related to a fluxion structure and a sheet structure. Many references to descriptions of one or several such structures are cited. The Duluth gabbro shows all three structures conspicuously.

In nearly all of the many references it is stated that the structure in the igneous rock shows a general parallelism to the contacts of the mass—that is, the structure developed under some control by its walls. There are so few exceptions that the structure may be safely used as a guide to form.

The origin of the structure has been discussed by several men. Eliminating those cases in which metamorphic banding or half-fused layers are indicated, the suggestions are: (1) Partial assimilation, (2) lit par lit, (3) deformation

[1] Introduced by W. H. Emmons.

during or just after solidification, (4) streaked differentiation, (5) successive intrusion, (6) heterogeneous intrusion. The writer would add (7) convection during crystallization.

Presented in abstract from notes.

Discussion

Dr. W. J. Miller: Doctor Grout should be congratulated on this paper. The Adirondack anorthosite shows many bands of varying mineral composition, but not as conspicuously as the Duluth gabbro, and the bands, so far as I have observed them, are extremely variable in dip and strike, with apparently no general parallelism to contacts. Possibly the laccolithic structure of the Adirondack anorthosite as opposed to the sill structure of the Duluth gabbro might account for the difference.

Dr. M. E. Wilson: To one who is constantly encountering the phenomenon of a banded structure in igneous rocks, Doctor Grout's paper is of special interest. There is one way, however, in which I think a banded structure might possibly develop in an igneous rock that Doctor Grout did not mention, and that is by diffusion during consolidation.

It is obvious that if a magma is homogeneous before consolidation commences, the development of individual crystals is in reality differentiation on a small scale. In some magmas this differentiation by crystal growth apparently continues until aggregates of crystals have developed and a rock of a very heterogeneous appearance is formed. If a magma in which this differentiation process was in progress was subject to differential pressure, it seems reasonable to suppose that the segregation would take place linearly, resulting in a banded structure. Many of the igneous Precambrian rocks of the Canadian Laurentian highlands are characterized by a minute discontinuous banding, the origin of which, it seems to me, can be best explained in this way.

Remarks were also made by Prof. James F. Kemp and Dr. M. E. Wilson.

TWO-PHASE CONVECTION IN IGNEOUS MAGMAS

BY FRANK F. GROUT [1]

(Abstract)

Convection is indicated by the banding in igneous rocks. It is observed in lava lakes and may be inferred from other rock structures. Convection in a deep magma chamber has usually been attributed to density differences due to temperature of the liquid. Daly also emphasizes the change of density due to a concentration of a gas phase. This paper emphasizes the density difference due to crystal phases.

The order of magnitude of the forces is estimated. The results of such two-phase convection are outlined.

Presented in abstract from notes.

[1] Introduced by W. H. Emmons.

Discussion

Answer of author to questions by Dr. W. J. Miller: Regarding the regularity in the structure and conformity to walls, I would say that I can not assume that conformity always occurs, but simply state that of 24 recorded cases only one exception was found. New records will be welcome. One should also note whether the irregularity is general or local.

HYDROUS SILICATE MELTS

BY N. L. BOWEN [1] AND G. W. MOREY [1]

(*Abstract*)

The system H_2O-K_2SiO_3-SiO_2 has been studied experimentally by Morey, with careful control and measurement of both temperatures and pressures. His results furnish a basis for the quantitative description of the behavior of the hydrous melts on cooling under various conditions of pressure and illustrate principles of general importance in the consideration of the behavior of magmas containing volatile components.

Read by title in the absence of the authors.

SIGNIFICANCE OF GLASS-MAKING PROCESSES TO THE PETROLOGIST

BY N. L. BOWEN [1]

(*Abstract*)

Glass-making processes offer little support to the belief in immiscibilty of silicate liquids. They do, however, emphasize that the stage at which the mass is partly liquid and partly solid (crystalline) is of great significance to one interested in the differentiation of igneous rocks. It is principally at this stage that different parts of the melt may acquire composition differences troublesome to the glass-maker, though instructive to the petrologist.

Read by title in the absence of the author.

TYPES OF NORTH AMERICAN PALEOZOIC OOLITES

BY FRANCIS M. VAN TUYL [2] AND HAROLD F. CROOKS [2]

(*Abstract*)

Through the cooperation of a number of geologists located in various parts of North America, it has been possible to assemble for study samples from nearly all known oolitic horizons of the Paleozoic. The varieties represented are calcareous, siliceous, phosphatic, and ferruginous. Microscopic study of these shows that they may be classified according to a few important structural types. These are described and the evidence bearing on the probable mode of origin of each is summarized.

Read by title in the absence of the author.

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[1] Introduced by H. S. Washington.
[2] Introduced by Eliot Blackwelder.

SILICEOUS OOLITES IN SHALE

BY W. A. TARR[1]

(*Abstract*)

The unusual occurrence of oolites in shale from the red beds is noted. The oolites are in a sandy shale of varying colors, red, yellow, and green predominating. The oolites are of two sizes, the larger averaging about .65 mm. and the smaller from .1 to .13 mm. They make up approximately 50 per cent of the rock. The large oolites are concentrically banded in their outer parts only. The oolites are believed to be original and to have been formed through the precipitation of colloidal silica along with the materials of the shale.

Read in full from manuscript.

INORGANIC PRODUCTION OF OOLITIC STRUCTURES

BY W. H. BUCHER[2]

(*Abstract*)

A preliminary account was given of the results of successful experiments made to prove that oolitic structure can be produced without the direct or indirect help of organisms in substances other than calcium carbonate. The bearing of these results on the origin of various oolitic sediments was discussed.

Artificial and natural specimens were exhibited.

Presented in full from notes.

DISCUSSION

Mr. E. G. WOODRUFF: There are publications describing oolites from oil wells at Sour Lake, Texas. These oolites are from an oil-producing well which is being pumped. The well is lined with strainer and openings too small to admit oolites, but will admit nuclei-forming materials. Saline solutions enter the well. The fluids are agitated and the salts are precipitated about any solid fragment in the well. Salts are deposited in concentric layers, forming oolites as large as one-fourth of an inch in diameter. These oolites are artificial.

Dr. G. H. COX: The tendency of colloidal materials to assume a circular form has now been appealed to by various authors to explain oolites and rounded forms. Are we therefore to assume that this is the natural structure of colloidal silica, and that therefore non-oolite cherts are of secondary origin?

Dr. A. R. CROOK: The statement that certain oolites lack nuclei should raise a question, since physicists and meteorologists know that raindrops always form around a nucleus of dust, it is reasonable to assume that oolites always have a nucleus, even though it may be so small as to escape detection.

Dr. E. V. EMERSON: In the Middle Eocene of Louisiana are beds of ostrea marl underlain by stiff plastic bluish clay. In some places there is a narrow zone in the clay, varying in width up to 10 inches, in which the clay has an apparent oolitic texture. The oolites have diameters up to 10 mm. and are

[1] Introduced by E. B. Branson.

[2] Introduced by Nevin M. Fenneman.

not indurated. Possibly they may be due to the descent of calcareous water which has flocculated the underlying clay.

Reply by author (Dr. W. A. Tarr) to questions: The fact that oolites might form from a colloidal silica gel at times and chert at other times can be explained by the rate of accumulation of the silica and the inclosing sediments, the movement of the water, and the amount of silica added. In the case of shales, the muds are added so fast in agitated waters that when the rate of addition of silica is sufficient oolites may form. In limestones the slow rate of accumulation permits the growth of large aggregates of silica. At other times the silica added goes down as the colloidal matter of the clay.

Remarks were also made by Dr. R. M. Bagg.

GLAUCONITE IN DOLOMITE AND LIMESTONE OF MISSOURI

BY W. A. TARR[1]

(Abstract)

Glauconite occurs in grains in the Burlington limestone (Mississippian) and in similar form, but in much larger amounts, in the Bonne Terre dolomite (Cambrian) in southeastern Missouri. It is associated with the lead ores in that district and was long mistaken for chlorite. The glauconite was deposited at the same time as the dolomite. A suggestion as to its origin is made.

Presented in abstract extemporaneously.

DISCOVERY OF FLUORITE IN THE ORDOVICIAN LIMESTONES OF WISCONSIN

BY RUFUS MATHER BAGG

(Abstract)

Fluorspar has never been recorded from the Ordovician galena beds in Wisconsin, though its absence has been repeatedly mentioned in the various geological reports of the State. References to this are cited and a brief discussion of this common associate of zinc-lead ores.

A short description of the occurrence of this mineral and some theoretical considerations as to its probable origin are given.

Other minerals present in the quarries where this mineral occurs are shown and the order of their deposition explained.

Presented in abstract extemporaneously.

Discussion

Dr. W. A. Tarr: Fluorite is found in crystals up to two inches across in geodes in the Saint Louis (Mississippi) limestone. It is usually the very last mineral to be deposited.

OCCURRENCE OF A LARGE TOURMALINE IN ALABAMA PEGMATITE

BY FRANK R. VAN HORN

(Abstract)

In the vicinity of Micaville, Randolph County, Alabama, there are many

[1] Introduced by E. B. Branson.

pegmatite dikes striking northwest and southeast. They range from 6 inches up to 40 feet in width and occur in what is locally called "Ashland mica schist." The chief minerals are quartz, orthoclase, muscovite, biotite, iron tourmaline, and beryl. The dikes are weathered to kaolinite to a depth of 60 to 90 feet from the surface. The quartz crystals are very large, sometimes weighing several hundred pounds, as is also true of the micas, which are found up to 300 pounds. On the other hand, the feldspars are seldom over a few inches in diameter. The tourmalines are commonly of all dimensions up to 10 by 6 inches in diameter, and the beryls are found up to 5 by 3 inches in diameter. At a depth of about 70 feet in the weathered dike a large crystal of iron tourmaline was found. The top of this crystal is now in the Museum of the Case School of Applied Science. The specimen is now 7 inches high and 10 inches in diameter and weighs 43½ pounds. Since it was originally 3 to 3½ feet long, it must have weighed from 225 to 250 pounds and therefore must have been one of the largest tourmalines ever found. The faces are rough and vertically striated, but the three planes of ∞ P $(10\bar{1}0)$ and the 6 of ∞ P 2 $(11\bar{2}0)$ are easily distinguishable. It is terminated by R $(10\bar{1}0)$, which is therefore the blunter end or antilogue pole.

Presented in full extemporaneously.

CAUSE OF THE ABSENCE OF WATER IN DRY SANDSTONE BEDS

BY ROSWELL H. JOHNSON [1]

(*Abstract*)

"Dry sands"—that is, sandstone beds without water—are to be explained on the supposition that the accumulation of gas within the sand has displaced water, which it originally held. Opposed to this view are Gardner, who writes, and Reeves, who urges, that "the sediments and their porous areas were filled with air, which later prevented water from penetrating them during submergence beneath the sea."

These views are held much more naively by many operators who talk of a "good sand," although it contains no gas, oil, or water and is in a region that is undrained, failing to realize the physical impossibility of such a condition, in view of the well known, world-wide increase of pressure with depth. Even in the rare cases when the gas is largely nitrogen we have high pressure also. No sand should be called good that is not porous, and if porous and not exhausted it must contain gas, oil, or water.

The proof that the "dryness" is caused by gas displacement of the connate water lies in the chemistry of the gas. Only in the very rare cases where this is mainly nitrogen is the Gardner or Reeves position tenable. What little nitrogen there is is probably entrapped air from which the oxygen has been removed by oxidizing compounds, the CO in the turn forming carbonates.

The Appalachian field which Reeves uses for evidence carries very little nitrogen, nor are the gases richest in nitrogen from red beds, but from sands in Kansas several hundred feet below the red beds.

Read by title in the absence of the author.

[1] Introduced by Charles P. Berkey.

VOTE OF THANKS

The following resolutions of thanks were passed unanimously: To the local committee, consisting of Messrs. Branson and Buehler, for the careful preparations for the meeting which had been made and for the wise care of all the Society's wants which had been exercised, and to the Saint Louis Publicity and Convention Committee, who had been largely instrumental in making the meeting possible and successful.

The Society adjourned at noon.

Register of the Saint Louis Meeting, 1917

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Sidney L. Galpin
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There were also 41 visitors who registered.

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George H. Barton, Boston Society of Natural History, Boston, Mass. August, 1890.
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Florence Bascom, Bryn Mawr College, Bryn Mawr, Pa. August, 1894.
Ray Smith Bassler, U. S. National Museum, Washington, D. C. Dec., 1906.
Edson S. Bastin, U. S. Geological Survey, Washington, D. C. Dec., 1909.
Alan Mara Bateman, Yale University, New Haven, Conn. December, 1916.
William S. Bayley, University of Illinois, Urbana, Ill. December, 1888.
*George F. Becker, U. S. Geological Survey, Washington, D. C.

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John Adams Bownocker, Ohio State University, Columbus, Ohio. Dec., 1904.
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Charles Butts, U. S. Geological Survey, Washington, D. C. December, 1912.
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Marius R. Campbell, U. S. Geological Survey, Washington, D. C. Aug., 1892.
Luiz Filippe G. de Campos, Geological Survey of Brazil, Rio de Janeiro, Brazil.
Charles Camsell, Geological Survey of Canada, Ottawa, Canada. Dec., 1914.
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Rollin T. Chamberlin, University of Chicago, Chicago, Ill. December, 1913.
*T. C. Chamberlin, University of Chicago, Chicago, Ill.
Clarence Raymond Claghorn, Claghorn, Pa. August, 1891.
Charles H. Clapp, University of Arizona, Tucson, Arizona. December, 1914.
Frederick G. Clapp, 120 Broadway, New York, N. Y. December, 1905.
John Mason Clarke, Albany, N. Y. December, 1897.
Herdman F. Cleland, Williams College, Williamstown, Mass. Dec., 1905.
J. Morgan Clements, 20 Broad St., New York City. December, 1894.
Collier Cobb, University of North Carolina, Chapel Hill, N. C. Dec., 1894.
Arthur P. Coleman, Toronto University, Toronto, Canada. December, 1896.

George L. Collie, Beloit College, Beloit, Wis. December, 1897.
Arthur J. Collier, U. S. Geological Survey, Washington, D. C. June, 1902.
D. Dale Condit, Cristobal, Canal Zone. December, 1916.
Charles W. Cook, University of Michigan, Ann Arbor, Mich. Dec., 1915.
Eugene Coste, 1943 11th St., West, Calgary, Alberta, Canada. Dec., 1906.
Ralph Dixon Crawford, University of Colorado, Boulder, Colo. Dec., 1916.
Alja R. Crook, State Museum of Natural History, Springfield, Ill. Dec., 1898.
*William O. Crosby, Massachusetts Institute of Technology, Boston, Mass.
Whitman Cross, U. S. Geological Survey, Washington, D. C. May, 1889.
Garry E. Culver, 310 Center Ave., Stevens Point, Wis. December, 1891.
Edgar R. Cumings, Indiana University, Bloomington, Ind. August, 1901.
*Henry P. Cushing, Western Reserve University, Cleveland, Ohio..
Reginald A. Daly, Harvard University, Cambridge, Mass. December, 1905.
Edward Salisbury Dana, Yale University, New Haven, Conn. Dec., 1908.
*Nelson H. Darton, U. S. Geological Survey, Washington, D. C.
*William M. Davis, Harvard University, Cambridge, Mass.
Arthur Louis Day, Geophysical Laboratory, Carnegie Institution, Washington, D. C. December, 1909.
David T. Day, 1333 F St. N. W., Washington, D. C. August, 1891.
Bashford Dean, Columbia University, New York, N. Y. December, 1910.
Alexander Deussen, University of Texas, Austin, Texas. December, 1916.
Frank Wilbridge De Wolf, Urbana, Ill. December, 1909.
*Joseph S. Diller, U. S. Geological Survey, Washington, D. C.
Edward V. d'Invilliers, 518 Walnut St., Philadelphia, Pa. December, 1888.
Richard E. Dodge, Dodge Farm, Washington, Conn. August, 1897.
Noah Fields Drake, Fayetteville, Arkansas. December, 1898.
John A. Dresser, 701 Eastern Townships Bank Bldg., Montreal, Canada. December, 1906.
*Edwin T. Dumble, 2003 Main St., Houston, Texas.
Arthur S. Eakle, University of California, Berkeley, Cal. December, 1899.
Charles R. Eastman, American Museum of Natural History, New York, N. Y. December, 1895.
Edwin C. Eckel, Munsey Building, Washington, D. C. December, 1905.
*Benjamin K. Emerson, Amherst College, Amherst, Mass.
William H. Emmons, University of Minnesota, Minneapolis, Minn. Dec., 1912.
*Herman L. Fairchild, University of Rochester, Rochester, N. Y.
Oliver C. Farrington, Field Museum of Natural History, Chicago, Ill. December, 1895.
Nevin M. Fenneman, University of Cincinnati, Cincinnati, Ohio. Dec., 1904.
Clarence N. Fenner, Geophysical Laboratory, Washington, D. C. Dec., 1911.
Cassius Asa Fisher, 711 Ideal Building, Denver, Colo. December, 1908.
August F. Foerste, 128 Rockwood Ave., Dayton, Ohio. December, 1899.
William E. Ford, Sheffield Scientific School, New Haven, Conn. Dec., 1915.
Myron L. Fuller, 134 W. Upsal St., Germantown, Pa. December, 1898.
Sidney L. Galpin, Iowa State College, Ames, Iowa.
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James H. Gardner, 510 New Daniel Bldg., Tulsa, Oklahoma. December, 1911.
Russell D. George, University of Colorado, Boulder, Colo. December, 1906.
*Grove K. Gilbert, U. S. Geological Survey, Washington, D. C.

ADAM CAPEN GILL, Cornell University, Ithaca, N. Y. December, 1888.
L. C. GLENN, Vanderbilt University, Nashville, Tenn. June, 1900.
MARCUS ISAAC GOLDMAN, U. S. Geological Survey, Washington, D. C. Dec., 1916.
JAMES WALTER GOLDTHWAIT, Dartmouth College, Hanover, N. H. Dec., 1909.
CHARLES H. GORDON, University Library, University of Tennessee, Knoxville, Tenn. August, 1893.
CLARENCE E. GORDON, Massachusetts Agricultural College, Amherst, Mass. December, 1913.
CHARLES N. GOULD, 1218 Colcord Bldg., Oklahoma City, Okla. Dec., 1904.
AMADEUS W. GRABAU, Columbia University, New York, N. Y. December, 1898.
WALTER GRANGER, American Museum of Natural History, New York, N. Y. December, 1911.
ULYSSES SHERMAN GRANT, Northwestern University, Evanston, Ill. Dec., 1890.
JOHN SHARSHALL GRASTY, University of Virginia, University, Va. Dec., 1911.
LOUIS C. GRATON, Harvard University, Cambridge, Mass. December, 1913.
HERBERT E. GREGORY, Yale University, New Haven, Conn. August, 1901.
FRANK COOK GREENE, 30 North Yorktown St., Tulsa, Okla.
GEORGE P. GRIMSLEY, 31st and Calvert Sts., Gilman 3-B, Baltimore, Md. August, 1895.
LEON S. GRISWOLD, Plymouth, Mass. August, 1902.
FREDERIC P. GULLIVER, 1112 Morris Bldg., Philadelphia, Pa. August, 1895.
WILLIAM F. E. R. GURLEY, University of Chicago, Chicago, Ill. Dec., 1914
BAIRD HALBERSTADT, Pottsville, Pa. December, 1909.
GILBERT D. HARRIS, Cornell University, Ithaca, N. Y. December, 1903.
JOHN BURCHMORE HARRISON, Georgetown, British Guiana. June, 1902.
CHRIS. A. HARTNAGEL, Education Building, Albany, N. Y. December, 1913.
JOHN B. HASTINGS, 1480 High St., Denver, Colo. May, 1889.
*ERASMUS HAWORTH, University of Kansas, Lawrence, Kans.
RAY VERNON HENNEN, West Virginia Geological Survey, Morgantown, W. Va. December, 1914.
OSCAR H. HERSHEY, Kellogg, Idaho. December, 1909.
DONNEL FOSTER HEWETT, U. S. Geological Survey, Washington, D. C. Dec., 1916.
RICHARD R. HICE, Beaver, Pa. December, 1903.
*ROBERT T. HILL, 702 Hollingsworth Bldg., Los Angeles, Cal.
RICHARD C. HILLS, Denver, Colo. August, 1894.
HENRY HINDS, U. S. Geological Survey, Washington, D. C. December, 1912.
FERDINAND FRIIS HINTZE, Lehigh University, South Bethlehem, Pa.
*CHARLES H. HITCHCOCK, 2376 Oahu Ave., Honolulu, Hawaiian Islands.
WILLIAM H. HOBBS, University of Michigan, Ann Arbor, Mich. Aug., 1891.
*LEVI HOLBROOK, P. O. Box 536, New York, N. Y.
ROY J. HOLDEN, Virginia Polytechnic Institute, Blacksburg, Va. Dec., 1914.
WILLIAM JACOB HOLLAND, Carnegie Museum, Pittsburgh, Pa. December, 1910.
ARTHUR HOLLICK, Staten Island Association of Arts and Sciences, New Brighton, S. I. August, 1898.
THOMAS C. HOPKINS, Syracuse University, Syracuse, N. Y. December, 1894.
WILLIAM OTIS HOTCHKISS, State Geological Survey, Madison, Wis. Dec., 1911.
*EDMUND OTIS HOVEY, American Museum of Natural History, New York, N. Y
ERNEST HOWE, 77 Rhode Island Ave., Newport, R. I. December, 1903.
GEORGE D. HUBBARD, Oberlin College, Oberlin, Ohio. December, 1914.

George H. Hudson, Plattsburg Normal School, Plattsburg, N. Y.
Walter F. Hunt, University of Michigan, Ann Arbor, Mich. December, 1914.
Ellsworth Huntington, 222 Highland St., Milton, Mass. December, 1906.
Louis Hussakof, American Museum of Natural History, New York, N. Y. December, 1910.
Joseph P. Iddings, Brinklow, Md. May, 1889.
John D. Irving, Yale University, New Haven, Conn. December, 1905.
A. Wendell Jackson, 9 Desbrosses St., New York, N. Y. December, 1888.
Robert T. Jackson, 195 Bay State Road, Boston, Mass. August, 1894.
Thomas Augustus Jaggar, Jr., Hawaiian Volcano Observatory, Territory of Hawaii, U. S. A. December, 1906.
Mark S. W. Jefferson, Michigan State Normal College, Ypsilanti, Mich. December, 1904.
Edward C. Jeffrey, Harvard University, Cambridge, Mass. December, 1914.
Albert Johannsen, University of Chicago, Chicago, Ill. December, 1908.
Douglas Wilson Johnson, Columbia University, New York, N. Y. Dec., 1906.
William Alfred Johnston, Geological Survey, Ottawa, Canada. Dec., 1916.
Alexis A. Julien, South Harwich, Mass. May, 1889.
Frank James Katz, U. S. Geological Survey, Washington, D. C. Dec., 1912.
George Frederick Kay, State University of Iowa, Iowa City, Iowa. Dec., 1908.
Arthur Keith, U. S. Geological Survey, Washington, D. C. May, 1889.
*James F. Kemp, Columbia University, New York, N. Y.
Charles Rollin Keyes, 944 Fifth St., Des Moines, Iowa. August, 1890.
Edward M. Kindle, Victoria Memorial Museum, Ottawa, Canada. Dec., 1905.
Charles T. Kirk, 327 S. Wheeling St., Tulsa, Okla. December, 1915.
Edwin Kirk, U. S. Geological Survey, Washington, D. C. December, 1912.
Cyril Workman Knight, Toronto, Ontario, Canada. December, 1911.
Adolph Knopf, U. S. Geological Survey, Washington, D. C. December, 1911.
Frank H. Knowlton, U. S. National Museum, Washington, D. C. May, 1889.
Edward Henry Kraus, University of Michigan, Ann Arbor, Mich. June, 1902
Henry B. Kümmel, Trenton, N. J. December, 1895.
*George F. Kunz, 401 Fifth Ave., New York, N. Y.
George E. Ladd, 6109 Brookville Road, Chevy Chase, Md. August, 1891.
Frederic H. Lahee, Massachusetts Institute of Technology, Cambridge, Mass.
Lawrence Morris Lambe, Department of Mines, Ottawa, Canada. Dec., 1911.
Henry Landes, University of Washington, University Station, Seattle, Wash. December, 1908.
Alfred C. Lane, Tufts College, Mass. December, 1889.
Esper S. Larsen, Jr., U. S. Geological Survey, Washington, D. C. Dec., 1914.
Andrew C. Lawson, University of California, Berkeley, Cal. May, 1889.
Willis Thomas Lee, U. S. Geological Survey, Washington, D. C. Dec., 1903.
James H. Lees, Iowa Geological Survey, Des Moines, Iowa. December, 1914.
Charles K. Leith, University of Wisconsin, Madison, Wis. Dec., 1902.
Arthur G. Leonard, State University of North Dakota, Grand Forks, N. Dak. December, 1901.
Frank Leverett, Ann Arbor, Mich. August, 1890.
Joseph Volney Lewis, Rutgers College, New Brunswick, N. J. Dec., 1906.
William Libbey, Princeton University, Princeton, N. J. August, 1899.
Waldemar Lindgren, Massachusetts Institute of Technology, Boston, Mass. August, 1890.

MIGUEL A. R. LISBOA, Caixa postal 829, Ave. Rio Branco 46-V, Rio de Janeiro, Brazil. December, 1913.

WILLIAM N. LOGAN, Indiana University, Bloomington, Ind.

FREDERICK BREWSTER LOOMIS, Amherst College, Amherst, Mass. Dec., 1909.

GEORGE DAVIS LOUDERBACK, University of California, Berkeley, Cal. June, 1902.

GERALD F. LOUGHLIN, U. S. Geological Survey, Washington, D. C. Dec., 1916.

ALBERT P. LOW, Department of Mines, Ottawa, Canada. December, 1905.

RICHARD SWANN LULL, Yale University, New Haven, Conn. December, 1909.

CHARLES T. LUPTON, Cosden Oil and Gas Company, Tulsa, Okla. Dec., 1916.

SAMUEL WASHINGTON MCCALLIE, Atlanta, Ga. December, 1909.

HIRAM D. MCCASKEY, U. S. Geological Survey, Washington, D. C. Dec., 1904.

RICHARD G. MCCONNELL, Geological and Natural History Survey of Canada, Ottawa, Canada. May, 1889.

DONALD FRANCIS MACDONALD, U. S. Geological Survey, Washington, D. C. December, 1915.

JAMES RIEMAN MACFARLANE, Woodland Road, Pittsburgh, Pa. August, 1891.

WILLIAM MCINNES, Geological and Natural History Survey of Canada, Ottawa, Canada. May, 1889.

PETER MCKELLAR, Fort William, Ontario, Canada. August, 1890.

GEORGE ROGERS MANSFIELD, 2067 Park Road N. W., Washington, D. C. December, 1909.

CURTIS F. MARBUT, Bureau of Soils, Washington, D. C. August, 1897.

VERNON F. MARSTERS, 316 Rialto Bldg., Kansas City, Mo. August, 1892.

GEORGE CURTIS MARTIN, U. S. Geological Survey, Washington, D. C. June, 1902.

LAWRENCE MARTIN, University of Wisconsin, Madison, Wis. December, 1909.

EDWARD B. MATHEWS, Johns Hopkins University, Baltimore, Md. Aug., 1895.

FRANCOIS E. MATTHES, U. S. Geological Survey, Washington, D. C. December, 1914.

W. D. MATTHEW, American Museum of Natural History, New York, N. Y. December, 1903.

THOMAS POOLE MAYNARD, 1622 D. Hurt Bldg., Atlanta, Ga. December, 1914.

WARREN JUDSON MEAD, University of Wisconsin, Madison, Wis. Dec., 1916.

OSCAR E. MEINZER, U. S. Geological Survey, Washington, D. C. December, 1916.

P. H. MELL, 165 East 10th St., Atlanta, Ga. December, 1888.

WALTER C. MENDENHALL, U. S. Geological Survey, Washington, D. C. June, 1902.

JOHN C. MERRIAM, University of California, Berkeley, Cal. August, 1895.

GEORGE P. MERRILL, U. S. National Museum, Washington, D. C. Dec., 1888.

HERBERT E. MERWIN, Geophysical Laboratory, Washington, D. C. Dec., 1914.

ARTHUR M. MILLER, State University of Kentucky, Lexington, Ky. Dec., 1897.

BENJAMIN L. MILLER, Lehigh University, South Bethlehem, Pa. Dec., 1904.

WILLET G. MILLER, Toronto, Canada. December, 1902.

WILLIAM JOHN MILLER, Smith College, Northampton, Mass. December, 1909.

HUGH D. MISER, U. S. Geological Survey, Washington, D. C. December, 1916.

FRED HOWARD MOFFIT, U. S. Geological Survey, Washington, D. C. Dec., 1912.

G. A. F. MOLENGRAAF, Technical High School, Delft, Holland. December, 1913.

HENRY MONTGOMERY, University of Toronto, Toronto, Canada. Dec., 1904.

ELWOOD S. MOORE, Pennsylvania State College, State College, Pa. Dec., 1911.

MALCOLM JOHN MUNN, Clinton Bldg., Tulsa, Okla. December, 1909.

*Frank L. Nason, West Haven, Conn.

David Hale Newland, Albany, N. Y. December, 1906.

John F. Newsom, Leland Stanford, Jr., University, Stanford University, Cal. December, 1899.

Levi F. Noble, Valyermo, Cal. December, 1916.

William H. Norton, Cornell College, Mount Vernon, Iowa. December, 1895.

Charles J. Norwood, State University, Lexington, Ky. August, 1894.

Ida Helen Ogilvie, Barnard College, Columbia University, New York, N. Y. December, 1906.

Cleophas C. O'Harra, South Dakota School of Mines, Rapid City, S. Dak. December, 1904.

Daniel Webster Ohern, University of Oklahoma, Norman, Okla. Dec., 1911.

Edward Orton, Jr., Columbus, Ohio. December, 1909.

Henry F. Osborn, American Museum of Natural History, New York, N. Y. August, 1894.

Robert W. Pack, U. S. Geological Survey, Washington, D. C. December, 1916.

Sidney Paige, U. S. Geological Survey, Washington, D. C. December, 1911.

Charles Palache, Harvard University, Cambridge, Mass. August, 1897.

William A. Parks, University of Toronto, Toronto, Canada. December, 1906.

*Horace B. Patton, 817 Fifteenth St., Golden, Colo.

Frederick B. Peck, Lafayette College, Easton, Pa. August, 1901.

Richard A. F. Penrose, Jr., 460 Bullitt Bldg., Philadelphia, Pa. May, 1889.

George H. Perkins, University of Vermont, Burlington, Vt. June, 1902.

Joseph H. Perry, 276 Highland St., Worcester, Mass. December, 1888.

William C. Phalen, U. S. Bureau of Mines, Washington, D. C. Dec., 1912.

Alexander H. Phillips, Princeton University, Princeton, N. J. Dec., 1914.

Louis V. Pirsson, Yale University, New Haven, Conn. August, 1894.

Joseph E. Pogue, Northwestern University, Evanston, Ill. December, 1911.

Joseph Hyde Pratt, North Carolina Geological Survey, Chapel Hill, N. C. December, 1898.

William Armstrong Price, Jr., West Virginia University, Morgantown, W.Va. December, 1916.

Louis M. Prindle, U. S. Geological Survey, Washington, D. C. Dec., 1912.

William F. Prouty, University of Alabama, University, Ala. Dec., 1911.

*Raphael Pumpelly, Newport, R. I.

Frederick Leslie Ransome, U. S. Geological Survey, Washington, D. C. August, 1895.

Percy Edward Raymond, Museum of Comparative Zoölogy, Cambridge, Mass December, 1907.

Chester A. Reeds, American Museum of Natural History, New York, N. Y. December, 1913.

Harry Fielding Reid, Johns Hopkins University, Baltimore, Md. Dec., 1892.

Leopold Reinecke, Geological Survey, Ottawa, Canada. December, 1916.

William North Rice, Wesleyan University, Middletown, Conn. August, 1890

John Lyon Rich, Army War College, Washington, D. C. December, 1912.

Charles H. Richardson, Syracuse University, Syracuse, N. Y. Dec., 1899.

George Burr Richardson, U. S. Geological Survey, Washington, D. C. December, 1908.

Heinrich Ries, Cornell University, Ithaca, N. Y. December, 1893.

Elmer S. Riggs, Field Museum of Natural History, Chicago, Ill. Dec., 1911.
Henry Hollister Robinson, Peabody Museum, New Haven, Conn. Dec., 1916.
Bruce Rose, Geological Survey, Ottawa, Canada. December, 1916.
Jesse Perry Rowe, University of Montana, Missoula, Mont. December, 1911.
Rudolf Ruedemann, Albany, N. Y. December, 1905.
John Joseph Rutledge, Experiment Station, Pittsburgh, Pa. Dec., 1911.
Orestes H. St. John, 1141 Twelfth St., San Diego, Cal. May, 1889.
Reno H. Sales, Anaconda Copper Mining Company, Butte, Mon. Dec., 1916.
Robert Wilcox Sayles, Harvard University, Chestnut Hill, Mass.
*Rollin D. Salisbury, University of Chicago, Chicago, Ill.
Frederick W. Sardeson, University of Minnesota, Minneapolis, Minn. December, 1892.
Thomas Edmund Savage, University of Illinois, Urbana, Ill. December, 1907.
Frank C. Schrader, U. S. Geological Survey, Washington, D. C. Aug., 1901.
Charles Schuchert, Yale University, New Haven, Conn. August, 1895.
Alfred R. Schultz, U. S. Geological Survey, Washington, D. C. Dec., 1912.
William B. Scott, Princeton University, Princeton, N. J. August, 1892.
Arthur E. Seaman, Michigan College of Mines, Houghton, Mich. Dec., 1904.
Elias H. Sellards, Tallahassee, Fla. December, 1905.
Joaquim Candido da Costa Seña, State School of Mines, Ouro Preto, Brazil. December, 1908.
Millard K. Shaler, 4 Bishopsgate E. C., London, England. December, 1914.
George Burbank Shattuck, Vassar College, Poughkeepsie, N. Y. Aug., 1899.
Eugene Wesley Shaw, U. S. Geological Survey, Washington, D. C. Dec., 1912.
Solon Shedd, State College of Washington, Pullman, Wash. Dec., 1904.
Edward M. Shepard, 1403 Benton Ave., Springfield, Mo. August, 1901.
Bohumil Shimek, University of Iowa, Iowa City, Iowa. December, 1904.
Hervey Woodburn Shimer, Massachusetts Institute of Technology, Boston, Mass. December, 1910.
Claude E. Siebenthal, U. S. Geological Survey, Washington, D. C. Dec., 1912.
*Frederick W. Simonds, University of Texas, Austin, Texas.
William John Sinclair, Princeton University, Princeton, N. J. Dec., 1906.
Joseph T. Singewald, Johns Hopkins University, Baltimore, Md. Dec., 1911.
Earle Sloan, Charleston, S. C. December, 1908.
Burnett Smith, Syracuse University, Skaneateles, N. Y. December, 1911.
Carl Smith, U. S. Geological Survey, Washington, D. C. December, 1912.
*Eugene A. Smith, University of Alabama, University, Ala.
George Otis Smith, U. S. Geological Survey, Washington, D. C. Aug., 1897.
Philip S. Smith, U. S. Geological Survey, Washington, D. C. Dec., 1909.
Warren Du Pré Smith, University of Oregon, Eugene, Oregon. Dec., 1909.
W. S. Tangier Smith, Lodi, Cal. June, 1902.
*John C. Smock, Trenton, N. J.
Charles H. Smyth, Jr., Princeton University, Princeton, N. J. Aug., 1892.
Henry L. Smyth, Harvard University, Cambridge, Mass. August, 1894.
Robert Speight, Christ Church, Canterbury College, New Zealand. Dec., 1916
Arthur Coe Spencer, U. S. Geological Survey, Washington, D. C. Dec., 1896.
*J. W. Spencer, 2019 Hillyer Place, Washington, D. C.
Frank Springer, U. S. National Museum, Washington, D. C. December, 1911.
Josiah E. Spurr, Bullitt Bldg., Philadelphia, Pa. December, 1894.

Joseph Stanley-Brown, 26 Exchange Place, New York, N. Y. August, 1892.
Timothy W. Stanton, U. S. National Museum, Washington, D. C. Aug., 1891.
Clinton R. Stauffer, University of Minnesota, Minneapolis, Minn. Dec., 1911.
Eugene Stebinger, Jr., U. S. Geological Survey, Washington, D. C. Dec., 1916.
Edward Steidtmann, University of Wisconsin, Madison, Wis. December, 1916.
Lloyd W. Stephenson, U. S. Geological Survey, Washington, D. C. Dec., 1911.
*John J. Stevenson, 215 West 101st St., New York, N. Y.
James Hough Stoller, Union College, Schenectady, N. Y.
Ralph Walter Stone, U. S. Geological Survey, Washington, D. C. Dec., 1912.
George Willis Stose, U. S. Geological Survey, Washington, D. C. Dec., 1908.
Charles K. Swartz, Johns Hopkins University, Baltimore, Md. Dec., 1908.
Stephen Taber, University of South Carolina, Columbia, S. C. Dec., 1914.
Joseph A. Taff, 781 Flood Building, San Francisco, Cal. August, 1895.
Mignon Talbot, Mount Holyoke College, South Hadley, Mass. Dec., 1913.
James E. Talmage, University of Utah, Salt Lake City, Utah. Dec., 1897.
William Arthur Tarr, University of Missouri, Columbia, Mo.
Frank B. Taylor, Fort Wayne, Ind. December, 1895.
*James E. Todd, 1224 Rhode Island St., Lawrence, Kans.
Cyrus Fisher Tolman, Jr., Leland Stanford, Jr., University, Stanford University, Cal. December, 1909.
Charles Weldon Tomlinson, University of Illinois, Urbana, Ill.
Arthur C. Trowbridge, State University of Iowa, Iowa City, Iowa. December, 1913.
*Henry W. Turner, 209 Alaska Commercial Building, San Francisco, Cal.
William H. Twenhofel, University of Wisconsin, Madison, Wis. Dec., 1913.
Mayville W. Twitchell, State Geological Survey, Trenton, N. J. Dec., 1911.
Joseph B. Tyrrell, Room 534, Confederation Life Building, Toronto, Canada. May, 1889.
Johan A. Udden, University of Texas, Austin, Texas. August, 1897.
Edward O. Ulrich, U. S. Geological Survey, Washington, D. C. Dec., 1903.
Joseph B. Umpleby, U. S. Geological Survey, Washington, D. C. Dec., 1913.
*Warren Upham, Minnesota Historical Society, Saint Paul, Minn.
*Charles R. Van Hise, University of Wisconsin, Madison, Wis.
Frank Robertson Van Horn, Case School of Applied Science, Cleveland, Ohio. December, 1898.
Gilbert van Ingen, Princeton University, Princeton, N. J. December, 1904.
Francis Maurice Van Tuyl, Colorado School of Mines, Golden, Colo.
T. Wayland Vaughan, U. S. Geological Survey, Washington, D. C. Aug., 1896.
Arthur Clifford Veach, 7 Richmond Terrace, Whitehall, S. W., London, England. December, 1906.
*Anthony W. Vogdes, 2425 First St., San Diego, Cal.
*M. Edward Wadsworth, School of Mines, University of Pittsburgh, Pittsburgh, Pa.
*Charles D. Walcott, Smithsonian Institution, Washington, D. C.
Thomas L. Walker, University of Toronto, Toronto, Canada. Dec., 1903.
Charles H. Warren, Massachusetts Institute of Technology, Boston, Mass. December, 1901.
Henry Stephens Washington, Geophysical Laboratory, Washington, D. C. August, 1896.

THOMAS L. WATSON, University of Virginia, Charlottesville, Va. June, 1900.
CHARLES E. WEAVER, University of Washington, Seattle, Wash. Dec., 1913.
WALTER H. WEED, 29 Broadway, New York, N. Y. May, 1889.
CARROLL H. WEGEMANN, U. S. Geological Survey, Washington, D. C. Dec., 1912.
SAMUEL WEIDMAN, Wisconsin Geological and Natural History Survey, Madison, Wis. December, 1903.
STUART WELLER, University of Chicago, Chicago, Ill. June, 1900.
LEWIS G. WESTGATE, Ohio Wesleyan University, Delaware, Ohio. Aug., 1894.
EDGAR T. WHERRY, Bureau of Chemistry, Washington, D. C. Dec., 1915.
DAVID WHITE, U. S. National Museum, Washington, D. C. May, 1889.
*ISRAEL C. WHITE, Morgantown, W. Va.
GEORGE REBER WIELAND, Yale University, New Haven, Conn. December, 1910.
FRANK A. WILDER, North Holston, Smyth County, Va. December, 1905.
*EDWARD H. WILLIAMS, JR., Woodstock, Vt.
*HENRY S. WILLIAMS, Cornell University, Ithaca, N. Y.
IRA A. WILLIAMS, Oregon School of Mines, Corvallis, Ore. December, 1905.
MERTON YARWOOD WILLIAMS, Geological Survey, Ottawa, Canada. Dec., 1916.
BAILEY WILLIS, Leland Stanford, Jr., University, Cal. December, 1889.
ALFRED W. G. WILSON, Department of Mines, Ottawa, Canada. June, 1902.
MORLEY EVANS WILSON, Geological Survey, Ottawa, Canada. December, 1916.
ALEXANDER N. WINCHELL, University of Wisconsin, Madison, Wis. Aug., 1901.
*HORACE VAUGHN WINCHELL, First National Society Bldg., Minneapolis, Minn.
*ARTHUR WINSLOW, 131 State St., Boston, Mass.
JOHN E. WOLFF, Harvard University, Cambridge, Mass. December, 1889.
JOSEPH E. WOODMAN, New York University, New York, N. Y. Dec., 1905.
ROBERT S. WOODWARD, Carnegie Institution of Washington, Washington, D. C. May, 1889.
JAY B. WOODWORTH, Harvard University, Cambridge, Mass. December, 1895.
CHARLES WILL WRIGHT, Ingurtosu, Arbus, Sardinia, Italy. December, 1909.
FREDERIC E. WRIGHT, Geophysical Laboratory, Carnegie Institution, Washington, D. C. December, 1903.
*G. FREDERICK WRIGHT, Oberlin Theological Seminary, Oberlin, Ohio.
GEORGE A. YOUNG, Geological Survey of Canada, Ottawa, Canada. Dec., 1905.
VICTOR ZIEGLER, Colorado School of Mines, Golden, Colo. December, 1916.

CORRESPONDENTS DECEASED

HERMAN CREDNER. Died July 22, 1913.
A. MICHEL-LÉVY. Died September, 1911.
H. ROSENBUSCH. Died January 20, 1914.
EDWARD SUESS. Died April 20, 1914.
TH. TSCHERNYSCHEW. Died Jan. 15, 1914.
FERDINAND ZIRKEL. Died June 11, 1912.

FELLOWS DECEASED

* Indicates Original Fellow (see article III of Constitution)

*CHAS. A. ASHBURNER. Died Dec. 24, 1889.
ALFRED E. BARLOW. Died May 28, 1914.
CHARLES E. BEECHER. Died Feb. 14, 1904.
ROBERT BELL. Died June 18, 1917.
ALBERT S. BICKMORE. Died Aug. 12, 1914.
WM. PHIPPS BLAKE. Died May 21, 1910.
AMOS BOWMAN. Died June 18, 1894.
AMOS P. BROWN. Died Oct. 9, 1917.
ERNEST R. BUCKLEY. Died Jan. 19, 1912.
D. D. CAIRNES. Died June 14, 1917.
*SAMUEL CALVIN. Died April 17, 1911.
FRANK. R. CARPENTER. Died April 1, 1910.
*J. H. CHAPIN. Died March 14, 1892.
WILLIAM B. CLARK. Died July 27, 1917.
*EDWARD W. CLAYPOLE. Died Aug. 17, 1901.
*THEO. B. COMSTOCK. Died July 26, 1915.

GEORGE H. COOK. Died Sept. 22, 1889.
*EDWARD D. COPE. Died April 12, 1897.
ANTONIO DEL CASTILLO. Died Oct. 28, 1895.
*JAMES D. DANA. Died April 14, 1895.
CHARLES A. DAVIS. Died April 9, 1916.
GEORGE M. DAWSON. Died March 2, 1901.
SIR J. WM. DAWSON. Died Nov. 19, 1899.
ORVILLE A. DERBY. Died Nov. 27, 1915.
CHAS. W. DRYSDALE. Died July 10, 1917.
CLARENCE E. DUTTON. Died Jan. 4, 1912.
*WILLIAM B. DWIGHT. Died Aug. 29, 1906.
*GEORGE H. ELDRIDGE. Died June 29, 1905.
*SAMUEL F. EMMONS. Died March 28, 1911.
WM. M. FONTAINE. Died April 29, 1913.
*ALBERT E. FOOTE. Died October 10, 1895.
*PERSIFOR FRAZER. Died April 7, 1909.
*HOMER T. FULLER. Died Aug. 14, 1908.
N. J. GIROUX. Died November 30, 1891.
ARNOLD HAGUE. Died May 14, 1917.
*CHRISTOPHER W. HALL. Died May 10, 1911.
*JAMES HALL. Died August 7, 1898.
JOHN B. HATCHER. Died July 3, 1904.
*ROBERT HAY. Died December 14, 1895.
C. WILLARD HAYES. Died Feb. 9, 1916.
*ANGELO HEILPRIN. Died July 17, 1907.
EUGENE W. HILGARD. Died Jan. 8, 1916.
FRANK A. HILL. Died July 13, 1915.
*JOSEPH A. HOLMES. Died July 13, 1915.
DAVID HONEYMAN. Died October 17, 1889.
*EDWIN E. HOWELL. Died April 16, 1911.
*HORACE C. HOVEY. Died July 27, 1914.
THOMAS S. HUNT. Died Feb. 12, 1892.
*ALPHEUS HYATT. Died Jan. 15, 1902.
THOMAS M. JACKSON. Died Feb. 3, 1912.
*JOSEPH F. JAMES. Died March 29, 1897.
WILBUR C. KNIGHT. Died July 28, 1903.
RALPH D. LACOE. Died February 5, 1901.
J. C. K. LAFLAMME. Died July 6, 1910.
DANIEL W. LANGTON. Died June 21, 1909.
*JOSEPH LE CONTE. Died July 6, 1901.
*J. PETER LESLEY. Died June 2, 1903.
ROBT. H. LOUGHRIDGE. Died July 1, 1917.
HENRY MCCALLEY. Died Nov. 20, 1904.
*W J MCGEE. Died September 4, 1912.
OLIVER MARCY. Died March 19, 1899.
OTHNIEL C. MARSH. Died March 18, 1899
*FRED. J. H. MERRILL. Died Nov. 29, 1916.
JAMES E. MILLS. Died July 25, 1901.
*HENRY B. NASON. Died January 17, 1895.
*PETER NEFF. Died May 11, 1903.
*JOHN S. NEWBERRY. Died Dec. 7, 1892.
WILLIAM H. NILES. Died Sept. 12, 1910.
*EDWARD ORTON. Died October 16, 1899.
*AMOS O. OSBORN. Died March, 1911.
*RICHARD OWEN. Died March 24, 1890.
SAMUEL L. PENFIELD. Died Aug. 14, 1906.
DAVID P. PENHALLOW. Died Oct. 20, 1910.
*FRANKLIN PLATT. Died July 24, 1900.
WILLIAM H. PETTEE. Died May 26, 1904.
*JOHN W. POWELL. Died Sept. 23, 1902.
*CHAS. S. PROSSER. Died Sept. 11, 1916.
A. H. PURDUE. Died Dec. 12, 1917.
*ISRAEL C. RUSSELL. Died May 1, 1906.
*JAMES M. SAFFORD. Died July 3, 1907.
*CHARLES SCHAEFFER. Died Nov. 23, 1903
H. M. SEELY. Died May 4, 1917.
*NATHANIEL S. SHALER. Died April 10, 1906.
WILLIAM J. SUTTON. Died May 9, 1915.
RALPH S. TARR. Died March 21, 1912.
WILLIAM G. TIGHT. Died Jan. 15, 1910.
CHARLES WACHSMUTH. Died Feb. 7, 1896
THOMAS C. WESTON. Died July 20, 1910
THEODORE G. WHITE. Died July 7, 1901.
*ROBERT P. WHITFIELD. Died April 6, 1910.
*GEORGE H. WILLIAMS. Died July 12, 1894
*J. FRANCIS WILLIAMS. Died Nov. 9, 1891
ARTHUR B. WILMOTT. Died May 8, 1914.
*ALEXANDER WINCHELL. Died Feb. 19, 1891
*NEWTON WINCHELL. Died May 1, 1914.
ALBERT A. WRIGHT. Died April 2, 1905.
WILLIAM S. YEATES. Died Feb. 19, 1908.

Summary

Correspondents	10
Original Fellows	41
Elected Fellows	365
Membership	416
Deceased Correspondents	6
Deceased Fellows	97

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 29, PP. 119-166 MARCH 31, 1918
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

PROCEEDINGS OF THE NINTH ANNUAL MEETING OF THE PALEONTOLOGICAL SOCIETY, HELD AT PITTSBURGH, PENNSYLVANIA, DECEMBER 31, 1917, AND JANUARY 1 AND 2, 1918.

R. S. BASSLER, *Secretary*

CONTENTS

Session of Monday, December 31

President Merriam called the Society to order in general session at 10 a. m., Monday, December 31, in Rehearsal Hall of the Carnegie Museum. Doctor Holland welcomed the Society to Pittsburgh in a patriotic speech, which was appreciated and warmly applauded by the members. Following Doctor Holland, President Merriam opened the exercises with an inspiring address, the keynote of which was our duty to science at the present dark moment.

The first matter of business before the Society was the report of the Council, which was then presented.

REPORT OF THE COUNCIL

To the Paleontological Society, in ninth annual meeting assembled:

This year's Council has held two regular meetings for the transaction of the Society's business—one at the adjournment of the meeting at Albany, December 29, and the second just before the present session. As usual, most of the business has been conducted by correspondence. The following reports of officers give a résumé of the administration for the ninth year of the Society:

SECRETARY'S REPORT

To the Council of the Paleontological Society:

Meetings.—The proceedings of the eighth annual meeting of the Society, held at Albany, New York, December 27-29, 1916, have been printed in volume 28, pages 189-234, of the Bulletin of the Geological Society of America, published on March 31, 1917. On account of the great delay in publication due to war conditions, only two numbers of the four published annually as the Bulletin of the Geological Society of America have been issued up to the present date, and the proceedings is the only one of our Society's publications that has so far been printed. Number four of this Bulletin, now in press, contains three articles by members of our Society. However, a second publication—an extensive paper by Doctor Grabau, published at the end of 1916—was distributed during the present year, so that while the number of papers has been smaller the number of printed pages has been about as usual.

The announcement that the ninth annual meeting of the Society would occur at Pittsburgh, Pennsylvania, beginning December 31, 1917, at the invitation of the Carnegie Museum, through the Director, Doctor William J. Holland, was forwarded to the members on March 26, 1917, with the Council's proposed nominations for officers.

At the meeting of the Council just concluded, it was voted that in view of the increased membership and business of the Society, the Secretary was empowered to expend not more than $25 per year for necessary clerical assistance.

Membership.—During the year the Society has lost by death Prof. Henry M. Seely, who died May 4, 1917, and Prof. William Bullock Clark, who died early in July, 1917. Professor Seely was one of our oldest members and had been Professor of Natural History at Middlebury College, Middlebury, Vermont, since 1861. His best known geologic work was on the stratigraphy and paleontology of the Beekmantown and Chazy

formations of the Champlain Valley. Professor Clark was in the prime of life, and his passing is a great blow to our science. His works on the Atlantic Coastal Plain, and especially on the geology and paleontology of Maryland, are too well known to be mentioned in detail.

Eight new members were elected to the Society at the eighth annual meeting, making the enrollment at the end of 1916, 184. Nine new members are under consideration for this meeting, so that at the present rate the Society will pass the 200 mark within a year. Five members of our Society were elected to Fellowship in the Geological Society of America at the election just concluded.

Pacific Coast Section.—The eighth annual meeting of the Pacific Coast Section of the Paleontological Society was held at Stanford University on April 6 and 7, 1917, the Society participating in the second annual meeting of the Pacific Division of the American Association for the Advancement of Science. On April 6 the Society met in joint session with the Geological Society and the Seismological Society, at which time Prof. John C. Merriam delivered an address on preparedness. This joint session adjourned at the conclusion of Professor Merriam's address, and the Paleontological Society was called to order in separate session by Dr. J. P. Buwalda at 3.15 o'clock, in room 360, Mineralogy Building.

The following officers were elected for the ensuing year:

President, Bruce L. Clark.
Vice-President, Chester Stock.
Secretary-Treasurer, Chester Stock.

Nineteen papers, dealing with both the Vertebrate and Invertebrate Paleontology and Stratigraphy of the West Coast especially, were read at this meeting. Twenty-two members and visitors were present. The minutes of this section are printed on pages 160 to 166 of this Bulletin.

Respectfully submitted,

R. S. Bassler,
Secretary.

Washington, D. C., *December* 31, 1917.

Treasurer's Report

To the Council of the Paleontological Society:

The Treasurer begs to submit the following report of the finances of the Society for the fiscal year ending December 19, 1917:

RECEIPTS

Cash on hand December 26, 1916		$481.65	
Membership fees (1916)		12.00	
Membership fees (1917)		243.10	
Interest, Connecticut Savings Bank		13.86	
			$750.61

EXPENDITURES

Treasurer's office:			
Postage	$4.00		
Stationery and printing	9.75		
		$13.75	
Secretary's office:			
Secretary's allowance	$50.00		
Expenses	47.49		
		97.49	
			111.24
Balance on hand December 19, 1917			$639.37
Net increase in funds			$157.72
Outstanding dues (1916), 4		$12.00	
Outstanding dues (1917), 9		27.00	
			39.00

Respectfully submitted,

Richard S. Lull,
Treasurer.

New Haven, Connecticut, *December* 19, 1917.

APPOINTMENT OF AUDITING COMMITTEE

Following the reading of the Treasurer's report, on vote of the Society, Burnett Smith and W. A. Parks were appointed a committee to audit these accounts.

ELECTION OF OFFICERS AND MEMBERS

The announcement of the election of officers for 1918 and of new members was the next matter of business. The results of the ballots were as follows:

OFFICERS FOR 1918

President:

F. H. Knowlton, Washington, D. C.

First Vice-President:

Arthur Hollick, New York City

Second Vice-President:

L. W. STEPHENSON, Washington, D. C.

Third Vice-President:

F. B. LOOMIS, Amherst, Mass.

Secretary:

R. S. BASSLER, Washington, D. C.

Treasurer:

R. S. LULL, New Haven, Conn.

Editor:

C. R. EASTMAN, New York City

NEW MEMBERS

F. E. CLEMENTS, Carnegie Institution, Washington, D. C.
LEE RAYMOND DICE, University of Montana, Missoula, Mont.
CHILDS FRICK, Santa Barbara, Cal.
EUGENE SCHOFIELD HEATH, Botany Hall, University of California, Berkeley, Cal.
REMINGTON KELLOGG, 2212 A Union, Berkeley, Cal.
WAYNE FREDERICK LOEL, Department of Geology and Mining, Stanford University, Palo Alto, Cal.
IDA CARTER OLDROYD, College Terrace, Palo Alto, Cal.
CARROLL MARSHALL WAGNER, 2604 Etna Street, Berkeley, Cal.

ELECTION OF NEW MEMBERS

The President then reported that the Council had acted favorably on the request of William F. E. Gurley, of Walker Museum, University of Chicago, and William A. Price, of West Virginia University, Morgantown, West Virginia, both members of the Geological Society of America, who had signified the wish to become members of the Paleontological Society. He also stated that the following nomination for membership, received too late for the printed ballot, was favored by the Council:

MRS. EULA D. MCEWAN, A. B. (1913), A. M. (1914) Indiana University, Scientific Aid in Paleontology, U. S. National Museum. Engaged in study of fossil invertebrates. Proposed by E. O. Ulrich and R. S. Bassler.

On motion by Mr. David White and the unanimous vote of the members, the Secretary was instructed to cast the ballot of the Society for election to membership of Messrs. Gurley and Price and Mrs. McEwan.

PRESENTATION OF PAPERS ON PALEONTOLOGY AND STRATIGRAPHY

The first paper on the program, dealing with the stratigraphy and paleontology of the Paleozoic rocks on the Piedmont plateau, was illustrated by lantern slides and was discussed by Messrs. Grabau and Merriam, with replies by the author.

PALEOZOIC DEPOSITS AND FOSSILS ON THE PIEDMONT OF MARYLAND AND VIRGINIA

BY R. S. BASSLER

(*Abstract*)

The western part of the Piedmont plateau in Maryland and Virginia contains areas of early Paleozoic limestone infolded in the Precambrian crystallines and overlaid in part by the Triassic (Newark) series. These limestones outcrop at one point next to the early Cambrian Harpers shale, and it has hitherto been believed that they represented the Shenandoah limestones of the Appalachian Valley, comprising strata from early Cambrian to Middle Ordovician time. Detailed mapping of this area and the discovery of fossils has shown that this Piedmont limestone consists of a lower massive limestone division with Lower Beekmantown fossils separated by a well marked disconformity from an upper thin bedded dark-blue limestone with a Chazyan fauna. The Lower Beekmantown division can be correlated directly with strata in the Appalachian Valley, but the Chazyan portion has no representation there.

There was then presented a study of an interesting problem in Devonian stratigraphy by the author, illustrated with diagrams, which brought forth discussion from several members of the Society.

SIGNIFICANCE OF THE SHERBURNE BAR IN THE UPPER DEVONIC STRATIGRAPHY

BY AMADEUS W. GRABAU

(*Abstract*)

The original Sherburne sandstone of Vanuxem formed a bar which extended from the old-land of Atlantica on the north to the mouth of the Devonic Romney River on the south. During its maximum development, shortly after the close of the Hamilton period, it was about ten miles wide and formed an effective barrier between the Atlantic region which carried the typical Hamilton fauna and western New York and the region beyond. In this area a remnant of the Hamilton fauna, cut off from intercrossing with the main stock, developed into the early Ithaca, or lower Portage fauna, to which were added migrants from the Traverse survivors of the west. Meanwhile the pure Hamilton, or Tropidoleptus, fauna continued in the embayment east of the bar, remaining in constant communication with the center of distribution of this fauna in the Atlantic. In the Far West the Naples fauna made its entrance,

so that three faunas existed simultaneously in New York—the Naples in the west, the Lower Portage, or pure Ithaca, in the center, and the Hamilton in the east. Submergence of the bar permitted an intermingling of the Hamilton and pure Ithaca faunas, and so produced the mixed fauna commonly taken as typical (but not the pure) Ithaca fauna. These facts are demonstrated by showing the percentages of each of the faunal units found in the successive sections from west to east.

Professor Moore, a visiting Fellow of the Geological Society of America, then gave an interesting account of algal limestones of the Far North. His paper was illustrated by lantern slides and was discussed by Messrs. White, Merriam, Grabau, and Bassler.

ALGAL LIMESTONE ON THE BELCHER ISLANDS, HUDSON BAY

BY E. S. MOORE [1]

(*Abstract*)

The Belcher Islands are situated off the east coast of Hudson Bay and consist of rocks similar in many respects to those formed on the coast and which have been described by Leith and Low. The islands were little known until recently, when considerable areas of jasper were discovered on them. Associated with this iron formation there is a remarkable band of concretionary limestone over 400 feet thick and consisting of spherical to subspherical balls varying from about an inch to 15 inches in diameter. These were at first regarded as cryptozoons, but their spherical form and the almost total absence of the crenulated character of the cryptozoons seem to separate them, at least from *Cryptozoon proliferum*. They resemble more strongly some of the recent algal concretions found in lakes and streams and described by Clarke, Roddy, and others. A smaller type is similar in some respects to Walcott's *Collenia? frequens*.

In the associated iron formation there are numerous granules of calcite, silica, and iron silicate. The two former bear a close resemblance to certain granules which occur in the Lower Paleozoic limestones of central Pennsylvania and which grade without break into distinct oolites. The occurrence of these concretions, both large and small, and their associations point strongly to organic origin of the limestone and iron deposits, and it indicates further that these rocks are either not Precambrian, as they have been supposed to be, or that an abundance of low types of life existed in the Hudson Bay basin in Precambrian time.

At 12.30 p. m. the Society adjourned for luncheon, convening again at 2 p. m. for the reading of the paleobotanic papers of the symposium. Although the absence of several of the authors prevented a full discussion of their papers, which were read by other members of the Society, a number of interesting and instructive points were brought out in the remarks by Messrs. Matthew, Vaughan, White, Merriam, Ami, Osborn, and others.

[1] Introduced by R. S. Bassler.

SYMPOSIUM ON PROBLEMS IN HISTORY OF FAUNAL AND FLORAL RELATIONSHIPS IN THE ANTILLEAN-ISTHMIAN REGION AND THEIR BEARING ON BIOLOGIC RELATIONSHIPS OF NORTH AND SOUTH AMERICA

RELATIONS BETWEEN THE PALEOZOIC FLORAS OF NORTH AND SOUTH AMERICA

BY DAVID WHITE

RELATIONS BETWEEN THE MESOZOIC FLORAS OF NORTH AND SOUTH AMERICA

BY F. H. KNOWLTON

PALEOGEOGRAPHIC SIGNIFICANCE OF THE CENOZOIC FLORAS OF EQUATORIAL AMERICA AND THE ADJACENT REGIONS

BY EDWARD W. BERRY

BEARING OF THE DISTRIBUTION OF THE EXISTING FLORA OF CENTRAL AMERICA AND THE ANTILLES ON FORMER LAND CONNECTIONS

BY WILLIAM TRELEASE

After the conclusion of the first part of the symposium, there was sufficient time before adjournment for the day for the presentation of the first paper in the list of those dealing with the invertebrate paleontology of Central America and the West Indies. This paper on the Paleozoic history was presented by the author and was illustrated by lantern slides of paleogeographic maps. Both the papers and the maps called forth such criticism and comments from Miss O'Connell and Messrs. Grabau, Matthew, Vaughan, and others that new data were added to this somewhat doubtful portion of Central American history.

PALEOZOIC HISTORY OF CENTRAL AMERICA AND THE WEST INDIES

BY R. S. BASSLER

At 5.30 p. m. the Society adjourned, meeting again at 8 p. m. at the University Club, to hear the address of the retiring President.

PRESIDENTIAL ADDRESS BY J. C. MERRIAM

AN OUTLINE OF PROGRESS IN PALEONTOLOGIC RESEARCH ON THE PACIFIC COAST

Doctor Merriam's account of the progress of all three branches of paleontology on the west coast was followed with much interest and attention by the fifty or more members and visitors who were present.

SMOKER TO THE SOCIETY

The presidential address was followed by a smoker to the Society as guests of Doctor Holland, Director of the Carnegie Museum. After refreshments had been served and conversation had continued for an hour, Doctor Holland, the host of the evening, called the Society to order and introduced one member after another for impromptu talks and reminiscences. The good stories related by Doctors Holland, Osborn, Williston, Ami, and Grabau, of American and foreign paleontologists, were especially enjoyed. The Society also had the pleasure of listening to addresses by the Chancellor of the University of Pittsburgh, members of the Board of Trustees of the Carnegie Museum, and other guests, and from several of the Fellows of the Geological Society of America. As the hour of 12 approached, Doctor Holland, in a patriotic address, emphasized the duty of science to the nation, and asked us to mark the passing of the old year with a pledge to our country. As the whistles of the great steel mills along the three rivers of Pittsburgh, the armorer of the nation, announced the birth of the New Year, we arose and pledged ourselves anew by the singing of "America."

Session of Tuesday, January 1

Tuesday morning, at 10 o'clock, the members met in the hall of vertebrate paleontology of the Museum and were shown all the choice specimens of the exhibit by Doctor Holland, who pointed out the most striking and interesting features in each. Time was lacking for a complete tour of the Museum, so Doctor Holland then guided us through the laboratories of vertebrate paleontology, where, with the magnificent specimens before us, he presented the following paper:

SOME OBSERVATIONS ON THE OSTEOLOGY OF DIPLODOCUS

BY WILLIAM J. HOLLAND

Questions and remarks by Doctors Osborn, Williston, and Matthews, with replies by Doctor Holland, added to this interesting discussion and gave the members an insight into the great explorations by the Carnegie Museum and its richness in vertebrate remains. The recently acquired material of Diplodocus in the possession of the Carnegie Museum, including a perfect skull, in which even the sclerotic coat of the left eye-ball had been petrified, was the especial subject of Doctor Holland's paper,

although he touched on and disposed of the recent criticisms of Rev. H. W. Hutchinson.

At 11.30 the Society commenced again in general session to continue the reading of papers, with Doctor Merriam presiding. The chairman announced that, in order to give variety to the program, papers from the three branches of paleontology would be interspersed. The first paper was a paleobotanic one, illustrated with specimens. Discussed by Messrs. Holland, Williston, Merriam, and Vaughan.

CRITICAL STUDY OF FOSSIL LEAVES FROM THE DAKOTA SANDSTONE

BY E. M. GRESS [1]

(*Abstract*)

The study has been based on a collection consisting of about 100 specimens. About 80 of these are from a large collection of fossils purchased from Baron Ernst de Bayet, of Brussels, a few years ago, the remainder from the United States National Museum by exchange. The Bayet collection comes from Ellsworth County, Kansas; the others from different parts of Kansas and Nebraska.

A few of the specimens had already been identified, some by Leo Lesquereux; others by an unknown person. Most of them bore no record of identification. All specimens have been carefully examined, and those bearing no labels have been identified, while those already identified have been verified.

The collection is represented by about 65 species and 25 genera, among which the most common are the following: Aralia, Betulites, Ficus, Magnolia, Populus, Protophyllum, Sassafras, Sterculia, and Viburnum.

In our study of the fossils we have included a brief review of the history, location, and correlation of the "Dakota Formation," with a careful description of each species and citations of available references. A critical study and comparison of each specimen with other described and figured species and with type forms has been made.

Professor Osborn then presented his interesting papers on vertebrate paleontology, both of which were illustrated by lantern slides. In the discussion of these papers Messrs. Holland, Merriam, Peterson, Granger, and Matthew took part.

OBSERVATIONS ON THE SKELETONS OF MOROPUS COOKI IN THE AMERICAN MUSEUM

BY HENRY FAIRFIELD OSBORN

(*Abstract*)

Moropus is the largest and most distinctive mammal of Lower Miocene time in western North America, and has attracted a great deal of attention from

[1] Introduced by O. E. Jennings.

paleontologists because of the long period of uncertainty as to its highly unique structure and adaptations and its great rarity as a fossil, the latter due probably to its forest-frequenting habits.

With its companions, the giant elothere pig, known as *Dinohyus*, and the diminutive pair-horned rhinoceros, *Diceratherium*, its remains have since 1882 been found in profusion in the Agate Spring Quarry of Sioux County, western Nebraska. This quarry lies in the upper portion of the Lower Harrison horizon of Hatcher and was discovered by Mr. James H. Cook, of Agate, in the year 1877. Prof. Erwin H. Barbour collected the first actual *Moropus* material from the Agate Springs quarries in July, 1892. Mr. Harold Cook made a considerable excavation in 1904, but it was not until 1908 that the specific name *Moropus cooki* was given by Professor Barbour[1] (January 26, 1908), thus identifying the animal generically with Marsh's type of *Moropus* from a somewhat more recent deposit.[2] In the meantime very extensive excavation and exploration was carried on by the Carnegie Museum for *Moropus*, *Dinohyus*, and *Diceratherium* remains, and after preliminary description the *Moropus* skeletons were described in detail in an important memoir in 1909.[3]

These carefully conducted excavations by Mr. O. A. Peterson, under Dr. W. J. Holland's direction, proved that the Agate Springs Quarry is the most remarkable deposit of mammalian remains of Tertiary age that has ever been found in any part of the world. Its only rival in the quantity of material preserved is the mid-Pleistocene deposit of Rancho La Brea, near Los Angeles, southern California.

In 1911, through the courtesy of Messrs. James H. Cook and Harold Cook and with their highly intelligent coöperation, the American Museum excavations began under the direction of Mr. Albert Thomson, assisted by Mr. Charles Barner, and continued through 1916.

In the year 1911, after exposing a large *Diceratherium* area of closely packed skeletal remains and securing parts of a *Dinohyus* skeleton, the border of a great *Moropus* area was exposed. In the year 1912 three skeletons of *Moropus* were secured, mingled with very abundant *Diceratherium* and portions of one skull and skeleton of *Dinohyus*. During 1913 and 1914 several more skeletons were found, and the outlines of a great *Moropus* bed were determined. In 1915 work was suspended. In 1916 the *Moropus* collections of the American Museum were completed (October 29), amounting in all to seventeen skeletons. In the five summers of excavation (1911-1914, 1916) an irregular area within a square of about thirty-six feet yielded nearly complete skulls of ten individuals and skeletal parts of seventeen more animals.

It was at first supposed that this accumulation of bones came from the drifting of a very large number of decomposing skeletons, but the early years of careful work soon revealed the very important fact that the greater part of this skeletal material belongs to a number of individuals. These individuals

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[1] E. H. Barbour: The skull of Moropus. Nebr. Geol. Survey, vol. 3, pt. 2, 1908, pp. 209-216, pls. 1-2, figs. 1-5.

[2] The type of *Moropus elatus* Marsh has recently been determined by Mr. Harold Cook as of Upper Harrison age.

[3] W. J. Holland and O. A. Peterson: The osteology of the Chalicotheroidea, with special reference to a mounted skeleton of *Moropus elatus* Marsh now installed in the Carnegie Museum. Mem. Carnegie Mus., vol. iii, no. 2, Jan. 17, 1914, pp. 189-406, pls. xlviii-lxxvii, figs. 1-113.

have been assembled with a considerable degree of certainty as to the association: first, through the extremely careful records which were kept of the location of every bone in the quarry; second, through their propinquity; third, the careful fitting and articulation of the bones; finally, through careful comparative measurement of size. It now appears certain that few of the bones had drifted a long distance; they were mostly deposited not far from the carcasses to which they had belonged.

The last twelve months of laboratory work in the American Museum of Natural History has resulted in bringing together several skeletons which are practically complete, and certainly in more than one case belonging to one individual, together with a number of skeletons in which the association of the bones is probably but not certainly correct.

From this wonderful material it has been possible to supplement the full descriptions of this animal which were published in 1909 by Messrs. Holland and Peterson, and to give for the first time the absolute form and proportions, the pose, and the articulations of the fully adult *Moropus*, of very large size. This and other materials will soon be described by the present author.

In the meantime *Moropus* may be characterized as a forest-loving, slow-moving animal, not improbably frequenting rather swampy ground. The small head, relatively long neck, high fore quarters, short, downwardly sloping back, straight and elongated limbs, suggest a profile contour only paralleled by the forest-loving okapi among existing mammals. The foot structure, of course, is radically different from that of the okapi, but we should not regard it as *fossorial*, or of the digging type, because it is not correlated with a fossorial type of fore limb. It would appear that these great fore claws, in which the phalanges were sharply flexed, were used in pulling down the branches of trees and also as powerful weapons of defense.

A LONG-JAWED MASTODON SKELETON FROM SOUTH DAKOTA AND PHYLOGENY OF THE PROBOSCIDEA

BY HENRY FAIRFIELD OSBORN

(*Abstract*)

Cope's family classifications were morphological and horizontal rather than phylogenetic and geological. Finding one or more single characters possessed in common at certain horizontal periods of geologic time by mammals in different lines of evolutionary descent, he seized on these common characters as convenient keys to classification. First [1] for the order Perissodactyla and then for the families of rhinoceroses [2] and titanotheres [3] I have reached the opinion that Cope's method of morphological classification is untenable, that the only true and permanent classification is phylogenetic. Other paleontologists, however, have reached a different opinion.

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[1] Fossil mammals of the Wasatch and Wind River beds. Collection of 1891. (With J. L. Wortman.) Bull. Am. Mus. Nat. Hist., vol. iv, art. xi, Oct. 20, 1892, pp. 81-147.

[2] Phylogeny of the rhinoceroses of Europe. Rhinoceros contributions No. 5. Bull. Am. Mus. Nat. Hist., vol. xiii, art. xix, Dec. 11, 1900, pp. 229-267.

[3] The four phyla of Oligocene titanotheres. Bull. Am. Mus. Nat. Hist., vol. xvi, art. viii, Feb. 18, 1902, pp. 91-109.

The chief advantage of the vertical phylogenetic classification is that it brings animals together in similar or closely allied lines of evolutionary descent; it corresponds with the branches and subbranches of the family tree. The chief difficulty with phylogenetic classification is a technical one, namely, to harmonize it with the Linnæan and the prevailing zoölogical systems of family, subfamily, and generic nomenclature, which are alike based on the affinities displayed between the existing terminal twigs of the branches and subbranches rather than on the phyletic ancestral lines which connect these twigs with their several ancestral branches. Sometimes the subfamilies proposed by zoölogists conform to the phyletic lines discovered by paleontologists; sometimes they do not.

The present classification and nomenclature of the Proboscidea illustrate afresh the confusion, at first glimpse apparently hopeless, resulting from the morphological classification and nomenclature of Linnæus and of various paleontologists, following the zoölogical standards, such as were embraced by Cope. Upward of forty generic names have been applied to the mastodons and elephants, and, as pointed out by Matthew,[6] there is no uniformity in the usage of these generic terms, nor has any principle of arrangement been worked out by which we may at least *begin* an advance toward a permanent system of nomenclature of this highly important and interesting group.

In the present paper, which is the result of studies begun in 1902 and of observations carried on in American and European museums, with the valuable aid of the recent rearrangement of the collections of Proboscidea in the American Museum of Natural History by Dr. W. D. Matthew, I essay a phylogenetic classification. This attempt, aided by the recent observations of Lull,[5] Matthew,[6] and Barbour,[7] is preliminary to a more thorough review which is in preparation by the author.[8]

It will probably subserve clearness to present at once the following key to the proposed phylogenetic classification, in which are shown at least *eleven* distinct phyla of proboscidians, grouped into *five* subfamilies and *three* families.

ORDER PROBOSCIDEA

Families

DINOTHERES:

I. *Dinotheriidæ*, crested teeth, down-turned tusks.

II. *Mastodontidæ*, crested and cone teeth.

MASTODONTS. A. Bunolophodont, cone-and-crest-teeth mastodonts.

1. *Bunomastodontinæ:*

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[5] R. S. Lull: The evolution of the elephant. Am. Jour. Sci., vol. xxv, Mar., 1908, pp. 169-212, figs. 1-27, 4 charts; reprinted in Smiths. Report for 1908, No. 1909, pp. 641-674.

[6] W. D. Matthew: The generic nomenclature of the Proboscidea. Read before the Paleontological Society, Pittsburgh, Jan. 1, 1918.

[7] E. H. Barbour: Mammalian fossils from Devils Gulch. Nebraska Geol. Survey, vol. 4, pt. i, Dec., 1913, pp. 177-190, pls. 1-13. A new longirostral mastodon from Cherry County, Nebraska. Nebraska Geol. Survey, vol. 4, pt. 14, Sept. 15, 1914, pp. 213-222, pls. 1-6, figs. 1-6 (tailpiece). A new longirostral mastodon from Nebraska, Tetrabelodon osborni, sp. nov. Am. Jour. Sci., vol. xli, June, 1916, pp. 522-529, figs. 1-4.

[8] A memoir on the phylogeny of the Proboscidea, with illustrations of the principal American types of mastodon and elephants in the American Museum of Natural History.

	MASTODONTS Bunomastodontinæ			Mastodontinæ	STEGODONTS Stegodontinæ	ELEPHANTS AND MAMMOTHS Loxodontinæ	Euelephantinæ		Elephantinæ
GENERA	**Trilophodon**	**Rhynchotherium**	**Tetralophodon**	**Mastodon**	**Stegodon**	**Loxodonta**	**Euelephas**		**Elephas**
RECENT	(longirostral)	(medirostral)	(brevirostral)			*a* L. africanus			E. indicus
PLEISTOCENE Lower			humboldtii	*a* M. americanus = ohioticus		L. antiquus L. namadicus	*b* E. primigenius E. trogontherii	E. columbi E. imperator	
PLIOCENE		*a* tlascalæ	andium	*b* borsoni	*a* ganesa		*c* E. meridionalis		
Upper Middle			*a* arvernensis *c* mirificus		Stegodon ?		*a* E. hysudricus *a* E. planifrons		
Lower 1	campester *c* morilli *d* tulli	euhypodon	*b* sivalensis		*b* S. clifti S. bombifrons				
Lower 2 - Pikermi	*b* longirostris punjabensis pentelicus		hasnoti		Stegodon ?				
	productus ? serridens floridanus	*b* ? shepardi	cautleyi						
MIOCENE Upper Upper Middle			perimensis		S. latidens				
Middle — St. Gaudens	macrognathus	brevidens							
Middle =St. Simorre	pandionis *a* angustidens								
	a (= leptodon)								
Lower	tapiroides (= turicensis)								
OLIGOCENE Burdig[n] Aquitan[n]	Palæomastodon Hemimastodon ? H. palæindicus								
Partial list of genera founded on species above	*a* Mastodon Cuv., 1817 ? *a* Gomphotherium ? Burmeister, 1837 *a* Trilophodon Falc., 1845-6 *a* Tetrabelodon Cope, 1884 *b* Tetralophodon Falc., 1857 *a* Mastotherium Fischer, 1814 *a* Gomphotherium Gloger, 1841 *a* Tetrabelodon Cope, 1884 *b* Tetralophodon Falc., 1857 *c* Eubelodon Barb., 1913 *d* Megabelodon Barb., 1914 *e* Zygolophodon Vacek, 1877 ?*a* Bunolophodon Vacek, 1877	*b* Dibelodon Cope, 1884 *a* Rhynchotherium Falc., 1857-1868	*a* Tetralophodon Warren, 1852 *a* Bunolophodon Vacek, 1877 *c* Stegomastodon Pohlig, 1910 *c* Rhabdobunus Hay *b* Pentalophodon Falc., 1857 *a* Anancus Aymard, 1855	*a* Mastodon Cuv., 1817 *a* Mammut Blum, 1799 *a* Harpagotherium Fisch. *a* Mastotherium Fischer, 1814 *a* Tetracaulodon Godman, 1830 *a* Missourium Koch, 1840 *a* Tetracaulodon Godman, 1830 *b* Zygolophodon Vacek, 1877 ? *a* Gomphotherium Burmeister, 1837	*a* Stegodon Falc., 1857 *b* Emmenodon Cope, 1889 *a* Stegolophodon Pohlig, 1888	*a* Loxodonta Cuv., 1827 *a* Loxodon Gray	*c* Archidiscodon Pohlig, 1888 *b* Dicyclotherium Geoffroy, 1837 *d* Euelephas Falconer, 1857 *b* Polydiscodon Pohlig, 1888		

1a. Longirostral, long-jawed, bunomastodonts, Africa, Eurasia, America.
1b. Rhynchotherine, beak-jawed, bunomastodonts, North America.
1c. Brevirostral, short-jawed, bunomastodonts, Asia, America.

B. ZYGOLOPHODONT:
2. *Mastodontinæ*, typical mastodonts of Europe, Asia, America.

III. *Elephantidæ:*

STEGODONTS. C. BRACHYLOPHODONT, short-crowned, crested teeth.
3. *Stegodontinæ*, stegodonts of southern Asia.

ELEPHANTS. D. HYPSILOPHODONT, long-crowned, crested teeth.
4. *Loxodontinæ:*
4a. *Loxodonta antiquus*, straight-tusked elephants, Eurasia, Africa.
4b. *Loxodonta africanus*, African elephants.
5. *Elephantinæ:*
5a. *Euelephas primigenius*, mammoths, Eurasia, North America
5b. *Euelephas columbi; E. imperator*, American mammoths.
5c. *Elephas indicus*, Indian elephants.

The three traditional families, namely, the *Dinotheriidæ*, *Mastodontidæ*, and *Elephantidæ*, call for no comment.

The mastodonts may be divided into two subfamilies, namely, (1) the *Bunomastodontinæ*, which are clearly distinguished by the presence of cones growing in between the transverse crests and forming "trefoils," to use the term introduced by Cuvier in his description of the grinding teeth of *M. angustidens*. This was the first bunomastodont discovered and is the type of a great race of longirostral, long-jawed, short-limbed forms, which ranged widely from northern Africa over Europe, Asia, and North America. As shown also in the accompanying scheme, the bunomastodonts, which sprang from *Palæomastodon* of the Oligocene of northern Africa and possibly as well from *Hemimastodon* of southern Asia, divide into three great, long-lived phyla, which may be distinguished as follows:

Longirostral, long-jawed, typified by the species *M. angustidens*.

Medirostral, beak-jawed, typified by *Rhynchotherium*.

Brevirostral, short-jawed, typified by the species *M. mirificus*.

The long-jawed and short-jawed phyla of bunomastodonts are comparatively well known in Europe, Asia, North and South America. The beak-jawed phylum, typified by the genus and species *Rhynchotherium tlaxcalæ*,[9] is provisionally arranged, because there is some uncertainty as to the position of the species *R. euhypodon* Cope, *R.* (?) *shepardi* Leidy, and *R. brevidens* Cope. The rhynchotherines are readily distinguished by jaws of medium length, which tend to turn downward into a long, depressed beak, somewhat like that of

[9] The specific name *tlaxcalæ* is suggested to the author by Dr. W. D. Matthew in reference to the locality in Mexico, Tlascala.

Dinotherium, in which the lower canines are laterally compressed, whereas in all the longirostral bunomastodonts the lower canines are vertically compressed.

All these *bunomastodontinæ* are very readily distinguished from the typical *Mastodontinæ*, a line which is relatively conservative in its evolution, since the "intermediate" molars remain trilophodont and the crests only feebly develop the intermediate cones, or trefoils. Singularly enough, the supposed north Asiatic ancestors of this phylum are not known. It first appears in the *M. borsoni* of the Pliocene of Europe.

The *Stegodontinæ* may be distinguished as a phylum confined to Asia, in which the grinding teeth remain brachyodont, short-crowned, although a very large number of cross crests evolve, especially on the posterior grinding teeth. From an early member of this subfamily, perhaps of Middle Miocene time, were given off one or more branches of the elephant and mammoth phyla.

Rhynchotherium from Mexico.—Extract of letter from Doctor Falconer to M. Lartet, September 12, 1856:[10] "At Genoa I saw a cast of a large lower jaw of a mastodon from Mexico, with an enormous *bec* abruptly deflected downwards and containing one very large lower incisor. The beak is much thicker than in *M.* (*Trilophodon*) *angustidens* and larger than in *M.* (*Tetralophodon*) *longirostris*. You know that every one (Laurillard, Gervais, etc.), have insisted on the absence of the lower incisors from both of the South American species. The outline of the jaw resembles very much the figure in Alcide D'Orbigny's Voyage, described by Laurillard as *M. andium*. The specimen is unpublished material and I was therefore only allowed to examine it very cursorily. The Genoese paleontologists had provisionally named it *Rhynchotherium*, from the enormous development of the beak, approaching Dinotherium."

The arrangement of the elephant and mammoth phyla is not clear at present, although it appears that four distinct subphyla developed. The first, to which the generic name *Loxodonta* applies, includes the Pleistocene and recent elephants of the African type, which by Falconer and other students of Asiatic forms are supposed to be related to the *L. namadicus* of the Lower Pliocene of the Siwaliks. The next phylum, *Euelephas*, by consent of all leading European authorities, begins with *E. planifrons* of Asia and Europe, Middle Pliocene. It includes *E. hysudricus* of the Upper Pliocene, passes into the *E. meridionalis* and *E. trogontherii* of the Lower Pliocene, and thence into *E. primigenius*, the woolly mammoth.

From a Middle Pliocene form, in a stage of evolution similar to that of *E. planifrons*, it is possible that the peculiarly American mammoths *E. columbi* and *E. imperator* may have been given off as a side phylum, but this is not yet determined. This leaves the typical elephant, *E. indicus*, as a related phylum, the ancestry of which has not yet been determined.

Thus the Proboscidea divide into at least six great phyla, to which the subfamily designations *Elephantinæ*, *Euelephantinæ*, *Loxodontinæ*, *Stegodontinæ*, *Mastodontinæ*, *Bunomastodontinæ*, may be given. There are also some reasons for separating the bunomastodonts into three phyla, which might be known as the *Longirostrinæ*, *Rhynchorostrinæ*, and *Brevirostrinæ*, but this may be a somewhat premature opinion.

[10] Charles Murchison: Paleontological Memoirs and Notes of the Late Hugh Falconer, A. M., M. D. 2 vols., 8vo. London, 1868, vol. ii, pp. 74-75.

This discrete and profuse subfamily arrangement would be shocking to a "lumper" like our late colleague and honored friend, Dr. Richard Lydekker, who combined[11] all the mastodons and elephants into two genera, namely, *Mastodon* and *Elephas*. The application of *subfamily* names to these monophyletic, or similar polyphyletic ascending series, is considered preferable to the coining of a new taxonomic term.

The propriety of thus applying subfamily terms is disputed by some paleontologists, notably by my colleagues, W. D. Matthew and W. K. Gregory. The subfamily termination, *inæ*, may, in the author's opinion, be adopted without any real exaggeration to express the fact that *many of these phyla have been distinct and separate from each other for enormous periods of geologic time.* This is real hereditary relationship in the family or subfamily sense. For example, it may be shown that the longirostral bunomastodont phylum began with *Palæomastodon* of the Upper Oligocene, and that this animal was already too specialized as a longirostral bunomastodont to constitute the ancestor of any other phylum than its own. This main longirostral phylum is geologically the oldest and phylogenetically the most complete. It illustrates one general law of mammalian evolution, namely, that a phylum having specialized in a certain character usually tends to evolve this character to an extreme; the long jaw of *Palæomastodon* goes on lengthening until in Lower Pliocene time it attains the great length observed in the forms recently described by Barbour[12] as *Eubelodon morrilli, Megabelodon lulli.*

In this longirostral phylum, as well as in the brevirostral bunomastodonts, the question of the application of the *generic* nomenclature of Linnæus is certainly a most puzzling one. Thirteen distinct generic names have been proposed for the longirostral bunomastodonts and six distinct generic names for the brevirostral bunomastodonts.

Several puzzling questions arise: first, how many generic names can consistently be applied within each of these phyla; second, which generic names in the long list shall be given precedence; third, shall the law of the technical priority of a name prevail, or shall we recognize only the priority of the first clear definition and conception of a genus which is based on one or more definite and clearly described characters of its genotypic species?

This whole question has been raised in the previous communication to the Paleontological Society by Doctor Matthew.[13] I am disposed to recommend that certain well defined generic names may, after due consideration, be adopted by the Paleontological Society as *nomina servantur.* The selection of these names will be greatly facilitated by a true phylogenetic classification of the Proboscidea, to which the present outline is preliminary.

At 12.30 the Society adjourned for luncheon.

CONTINUATION OF SYMPOSIUM

At 2 p. m. the symposium was resumed, with the reading of a paper on the Mesozoic history by Doctor Stanton entitled

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[11] Richard Lydekker: Catalogue of the Fossil Mammalia in the British Museum (Natural History). Pt. IV, The Order Ungulata, Suborder Proboscidea. 8vo. London, 1886, pp. xxiv, 233 (1).

[12] E. H. Barbour: Op. cit.

[13] W. D. Matthew: Op. cit.

MESOZOIC HISTORY OF CENTRAL AMERICA AND THE WEST INDIES

BY T. W. STANTON

Discussion of this paper was deferred until the last one of the series of invertebrate paleontology was presented by the author, Doctor Vaughan.

CENOZOIC HISTORY OF CENTRAL AMERICA AND THE WEST INDIES

BY T. W. VAUGHAN

A general review of the problems connected with the history offered by invertebrate paleontology was brought out in the discussion of these papers, which occurred at this point. Prominent among the speakers were Messrs. Holland, Osborn, Vaughan, Merriam, Matthew, and Grabau.

The evidence on this history offered by vertebrate paleontology was given in the two following papers, discussion again being deferred:

RELATIONSHIPS OF THE MESOZOIC REPTILES OF NORTH AND SOUTH AMERICA

BY S. W. WILLISTON

AFFINITIES AND ORIGIN OF THE ANTILLEAN MAMMALS

BY W. D. MATTHEW

This portion of the symposium called forth still more discussion, in which Messrs. Merriam, Matthew, Osborn, Eigenmann, Grabau, Williston, and Price participated. During this discussion, Doctor Eigenmann was requested to give the evidence afforded by the fishes. His remarks entitled as below were highly interesting and appreciated.

FRESH-WATER FISH FAUNAS OF NORTH AND SOUTH AMERICA

BY C. H. EIGENMANN

In this discussion Doctor Grabau mentioned the work and results of Graham J. Mitchell on recent changes of level in Porto Rico.

EVIDENCE OF RECENT CHANGES OF LEVEL IN PORTO RICO, AS SHOWN BY STUDIES IN THE PONCE DISTRICT[1]

BY GRAHAM JOHN MITCHELL[2]

(*Abstract*)

With the inauguration of the Natural History Survey of Porto Rico, under the joint auspices of the New York Academy of Sciences and the Insular Gov-

[1] By permission of the Porto Rico Committee of the New York Academy of Sciences. Report on the geology of the Ponce district in preparation.

[2] Introduced by A. W. Grabau.

ernment of the Island, a study of the geology of the region was undertaken as one phase of the investigations. The first geological party to enter the field consisted of Doctors Charles P. Berkey and Clarence N. Fenner, who, during the summer of 1914, completed a reconnaissance of the island. Since that time an average of two parties a year have been sent into the field.

In his report[3] Doctor Berkey noted the occurrences of terraces 100 to 200 feet above the present sealevel, particularly on the south coast near Guayama, and attributed their origin to wave action. Subsequent investigators have substantiated this conclusion. Mr. A. K. Lobeck, however, after a study of the physiography of the island, concluded that there has been only a slight differential uplift of the western end of Porto Rico in very recent time, the maximum change being at Rincon, on the west coast, where an elevation of 40 feet occurs.

During the past summer a survey of the southwestern quarter of the island was made by the writer, that section being one which appeared favorable to the solution of the question of recent changes of level in Porto Rico. The evidence gathered in this study is summed up as follows:

1. One-half mile southwest of Juana Diaz, on the north bank of the Jacaguas River, the folder Tertiary beds are beveled and a deposit of silt, sand, and gravel 2 to 12 feet thick covers the surface. In this surface covering, at an elevation of 130 feet, are found numerous *Strombus pugilis*.

2. At kilometer 72.5 on the Ponce-Penuelas road recent marine fossils are found in finely stratified material of estuarine character. In this deposit a layer of black mud averaging one foot in thickness occurs at a depth of from 2 to 5 feet below the surface. In this black mud are found *Strombus pugilis*, *Lucina jamaicensis*, *Lucina tigrina*, *Arca tuberculosa*, and *Byssoarca ziebra*. These fossils are also found in other parts of this deposit, the elevation of which is 180 feet.

3. Across the west branch of the Canas River, just east of the above locality, the same species of fossils which occur at locality "2" are found in the stratified sands and gravels at a depth of 3½ feet below the surface and an elevation of 160 feet.

4. Southeast of Yauco, 1¼ miles, in the Rio Yauco Valley, abundant fossils are found in the surface covering of the river valley at an elevation of 150 feet. The fossils include *Murex elongatus*, *Arca rhombea*, *Lucina tigrina*, *Arca tuberculosa*, *Turritella imbricata*, *Pecten nucleus*, *Venus cancellata*, *Ostrea virginica*, and *Perna* sp.

5. East of Yauco, one-eighth of a mile, the pre-Tertiary rocks are truncated, and in the gravel and sand which mantels the beveled strata are found *Arca tuberculosa* and *Lucina tigrina*, occurring at depths of 1 to 2 feet below the surface. The elevation at this point is 200 feet.

6. On the coast southeast of Yauco a terraced surface bevels the Tertiary limestone at an elevation of 60 to 160 feet, the inner margin being marked in places by cliffing. The following fossils are found on this surface: *Strombus accittrinna*, *Fissurella nodora*, *Arca rhombea*, and *Turbo pica*.

7. Just north of the lighthouse at Guanica the Tertiary limestone is beveled by terraces at levels of 10, 50, and 150 feet, and in the surface soil on the two

[3] Geological reconnaissance of Porto Rico. Annals N. Y. Academy of Sciences, vol. 26. 1916.

upper terraces are found *Arca tuberculosa*, *Lucina tigrina*, and *Turbo pica*. On the 10-foot level large numbers of these fossils are found in the lime, sand, and silt which coats this terrace.

8. East of Guanica, one-eighth of a mile, on the east side of the Susua Valley, a terrace at an elevation of 50 feet contains in the surface material the forms *Lucina jamaicensis*, *Arca tuberculosa*, and *Turbo pica*.

9. At the town of Ensenada (Central Guanica), the pre-Tertiary is truncated and a deposit of shells, muds, silt, and sand covers the surface to a maximum depth of 5 feet. The fossils occur at an elevation of 45 feet and include the following: *Murex elongatus*, *Isophyllia* sp., *Venus cancellata*, *Operculum of Turbo*, *Arca rhombea*, *Cerithium litteratum*, *Ostrea virginica*, and *Byssoarca ziebra*.

10. On the south side of Pardas Bay, south of Ensenada, the Tertiary limestone is again terraced, its elevation being 65 to 100 feet, and the fossils *Arca rhombea*, *Arca tuberculosa*, and *Lucina jamaicensis* are found buried in the surface soil.

11. On Cape Rojo, in the southwest corner of Porto Rico, the San Juan formation, which has been interpreted by Doctor Berkey as a limesand of dune origin, is found at an elevation of 75 feet overlain by 3 feet of conglomerate consisting of well rounded pebbles. In the San Juan formation occurs a *Conus* very close to the recent form *Conus porto-ricanus*.

12. On Aguilla Point, the extreme southwestern portion of the island, recent gastropod shells are found in consolidated gravels at an elevation of 11 feet. At an elevation of 25 feet they occur on the beveled surfaces of the rocks which make up this point.

13. Three and three-quarters miles southwest of Mayaguez, on the coast near the reform school, a terrace is cut on the pre-Tertiary rocks at an elevation of 50 feet. The inner margin is marked by cliffing, and the following fossils are found in the surface soil: *Arca tuberculosa*, *Venus cancellata*, and *Lucina jamaicensis*.

The argument has been advanced by Mr. Lobeck that where recent fossils have been found in Porto Rico they are associated with Indian mounds. Such an interpretation, however, could not explain the existence of recent shells buried in stratified material of estuarian character at depths of from 2 to 5 feet. Furthermore, although in each of the 13 localities cited above the writer made careful search for artifacts, in no instance was evidence found to substantiate the Indian mound theory.

Based on the evidence presented in the 13 above-mentioned cases, the writer draws the following conclusions: With the recent changes of level of land and sea the old river valleys were embayed, allowing the sea to enter with its marine fauna and to lay down deposits of sand, silt, and mud. That these deposits (for example, localities No. 1, 2, 3, 4, 5, 8, and 9) were laid down in Quaternary time is evidenced by the fact that over 95 per cent of the fossils are of the same species as those living at the present time in the adjacent sea.

In the remaining instances (6, 7, 10, 11, 12, 13) the truncation of the underlying beds of limestone and other formations along the south and west coasts and the presence of cliffing at the inner margins of some of these terraces, together with the recent fossils found on the surface, are facts hard to explain if they are not in some way connected with the work of the sea.

In considering the question, Which has been the shifting element, the land or the sea? the evidence indicates a change in the elevation of the land. If the sealevel had varied, one should find some uniformity in terrace levels at particular stages. Such uniformity does not exist. In summing up the conclusions the writer feels justified in stating that there has been differential uplift of the land in Porto Rico in recent time, with a maximum change of 200 feet.

PRESENTATION OF PAPERS

After the completion of the symposium, the hour for adjournment not having arrived, the reading of papers was resumed with the presentation of an interesting account of the great confusion prevailing in the nomenclature of the Proboscidea. As a result of this paper, it was voted by the Society that the President should appoint a committee to consider the generic nomenclature of the Proboscidea and other groups of mammals and to report its recommendation at the next meeting. Doctor Matthew was appointed chairman of this committee.

GENERIC NOMENCLATURE OF THE PROBOSCIDEA

BY W. D. MATTHEW

(Abstract)

The nomenclature of the extinct Proboscidea is in a state of fearful confusion. Partial attempts to apply the rules of strict priority have made matters worse, and a consistent application of the rules will apparently result in setting aside every one of the names in current use, but the proper substitute names would require a whole series of arbitrary or questionable decisions. As it is wholly improbable that such substitute names would be uniformly, or even generally, accepted, and as the object of nomenclatorial procedure is to secure uniformity, the writer proposes that certain of the current names be submitted as *nomina conservanda* to the committee of the International Zoological Congress with the indorsement of the Paleontological Society.

At 6 p. m. the Society adjourned.

Tuesday evening the members and invited guests attended the annual dinner of the Society at the University Club.

SESSION OF WEDNESDAY, JANUARY 2

Wednesday morning, at 10 o'clock, the Society met in general session, with Vice-President Matthew in the chair.

REPORT OF THE AUDITING COMMITTEE

The only matter of business on hand was the report of the committee to audit the accounts of the Treasurer. The committee attested to the

correctness of these accounts, and it was thereupon voted by the Society that the report be accepted.

PRESENTATION OF PAPERS

The first paper of the morning was an interesting account of the Cretaceous strata of northwest Europe as interpreted from the fossil sponges. This was presented by the author and illustrated with a number of diagrams. It brought forth considerable discussion, in which Messrs. Reeds, Grabau, Merriam, Dickerson, and Holland took part, with replies by Miss O'Connell.

CRETACEOUS OVERLAPS IN NORTHWEST EUROPE AND THEIR BEARING ON THE BATHYMETRIC DISTRIBUTION OF THE CRETACEOUS SILICISPONGIÆ

BY MARJORIE O'CONNELL

(*Abstract*)

While studying and arranging a collection of over a thousand specimens of Cretaceous Silicispongiæ in the American Museum of Natural History, the author was led to consider the lithic character and areal distribution of the sediments in which these fossils were found and the problem of the bathymetric range of European Cretaceous Silicispongiæ. The bathymetric ranges of Cretaceous species which have persisted to the present time will be given and there will be a brief discussion of the conclusions which it is permissible to draw from such data. The significance of the overlaps of the sponge-bearing and other Cretaceous strata of Europe will be considered and the value of the lithogenetic method of study in the determination of habits of ancient organisms will be dwelt on.

The next paper, which was amply illustrated by very clear and interesting lantern slides, was of especial interest on account of dealing with the region considered in the symposium. It was presented by the author, who replied to discussions by Messrs. Burling and Matthew.

NEW BATHYMETRICAL MAP OF THE WEST INDIES REGION

BY CHESTER A. REEDS

(*Abstract*)

During 1916 all of the Hydrographic and Coast and Geodetic Survey charts bearing on the West Indian region were assembled and, with chart 1290 as a base, all soundings were plotted. The one-hundredth fathom line was then drawn, also the five hundredth, and with a contour interval of 500 fathoms successive depths were sketched down to 4,500 fathoms. The result is a contour map somewhat different from its predecessors. When modeled on a globe surface the features of the submarine topography are even more striking.

Doctor Grabau then presented a study of one of the factors in faunal development, which brought forth considerable discussion from Messrs. Reeds, Parks, Williston, Matthew, Ortman, Merriam, and Bassler. This paper was illustrated by paleogeographic maps showing the development of North America in Silurian and Devonian times.

ISOLATION AS A FACTOR IN THE DEVELOPMENT OF PALEOZOIC FAUNAS

BY AMADEUS W. GRABAU

(Abstract)

Whenever a portion of a cosmopolitian fauna is segregated in an embayment of the Red Sea type, the segregated fauna being in large measure prevented from intercrossing with the main stock, and so remaining true to type, develops orthogenetically into a modified fauna which, when once established, remains true to the new type and frequently thereafter becomes a dominant one. The faunas which it is believed have thus come into existence are, among others, the Brassfield fauna of the Siluric, the Helderbergian fauna of the Lower Devonic, the eastern Michigan and Ontario Upper Hamilton fauna, and the Ithaca fauna. Illustrations of these will be given.

At 12.30 the Society adjourned for luncheon.

At 2 p. m. the members were called to order by Vice-President Grabau; who announced that by curtailing the longer papers somewhat separate sessions would not be necessary to complete the program.

The first paper of the afternoon session was presented by the Secretary for the author and dealt with new discoveries in the early Paleozoic rocks of Alaska.

AN ORDOVICIAN FAUNA FROM SOUTHEASTERN ALASKA

BY EDWIN KIRK

(Abstract)

The oldest fossiliferous sediments hitherto known in southeastern Alaska were of Silurian age. The discovery last season of early Ordovician sediments is therefore of considerable interest.

Extending along the shore for a considerable distance to either side of the town of Wrangell is a great series of highly metamorphosed sediments. These consist almost entirely of greenstones, crystalline schists, and argillites. A block of fossiliferous slate was found near Wrangell by Prindle some years ago. These fossils were reported by Girty as being anything from Devonian to Recent in age. If Paleozoic, he suggested that the age was probably Devonian or Carboniferous. The fossils were in a very poor state of preservation, and the prevailing opinion has been that the block of slate was an erratic. The beds at Wrangell have generally been assigned to the mainland belt of supposed Carboniferous-Mesozoic, that ranges from the Ketchikan area at the south to the Juneau and Chilkat areas at the north.

On the point forming the south side of Wrangell harbor, graptolites were found that seem to fix the age of this Wrangell series. The graptolites are found both in slate and schist. The slate specimens are unrecognizable unless one knows they are graptolites to begin with. The specimens occurring in the schist, though badly preserved, are easily recognizable as graptolites, and the generic affinities of one individual may be determined with a fair degree of certainty.

The specimen of chief importance and interest is referred with little doubt to *Tetragraptus*. It is very like a large species known in the early Ordovician of Idaho. Other specimens not so well preserved strongly suggest *Phyllograptus*. These fossils clearly point to the Beekmantown age of the sediments.

On Long Island and on Dall Island, on the southwest coast of Prince of Wales Island, are schistose sediments similar to those at Wrangell. They are even more metamorphosed than the Wrangell series where I saw them, and it seems doubtful if fossils would be preserved in them. They may well be of the same age, however. These beds fall in Brooks Wales series. As defined, the Wales series also probably included rocks of Silurian age.

Aside from establishing the presence of Ordovician sediments in southeastern Alaska, this find is of interest as throwing in doubt the generally accepted views as to the age of the mainland belt of sediments west of the Coast Range batholith. It has generally been assumed that this belt was of Carboniferous and Mesozoic age, with the Mesozoic as the more important element. It will probably be found that, in addition to the Carboniferous and Mesozoic, which are undoubtedly present at some points, all the Paleozoic elements elsewhere known in southeastern Alaska are represented in this coastal belt.

A brief summary of an extensive paper on the extinct Camelidæ was then presented by the author and was discussed by Messrs. Peterson and the author.

AFFINITIES AND PHYLOGENY OF THE EXTINCT CAMELIDÆ

BY W. D. MATTHEW

(*Abstract*)

The author has in preparation a revision of the extinct Camelidæ, preliminary results of which are presented. The relationship of the supposed Eocene ancestors of the Camelidæ is discussed, but they are not included in the family. The North American genera and species are revised and their relations are discussed. They afford exceptionally direct phyla from Oligocene to Pleistocene, with two distinct side branches, the giraffe-camels and gazelle-camels, and several minor twigs. The Old World camels belong to the genera *Pliauchenia* and *Camelus*, the latter not found in America, and are of Pliocene to recent age. The South American camels form a compact group of two closely related genera, *Palæolama* and *Auchenia*, and are of Pleistocene and recent age. Their nearest North American relatives are the smaller species of *Camelops* (Pleistocene), and they are doubtless derived from *Pliauchenia*, but not from any known species.

The two following papers on the stratigraphy and paleontology of the Canadian Cordillera were presented together by Mr. Burling, who illustrated them by diagrams and maps. Results of this stratigraphic work by Mr. Drysdale and Mr. Burling, the former of whom lost his life in this field-work, were discussed by Messrs. Parks, Grabau, and Burling.

ROCKY MOUNTAINS SECTION IN THE VICINITY OF WHITEMANS PASS

BY C. W. DRYSDALE AND L. D. BURLING

(*Abstract*)

This paper will describe the results of the fatal reconnaissance trip undertaken by the late Mr. Drysdale and the writer during the early part of the last field season.

The line of section begins west of Cochrane, Alberta, and proceeds in an almost straight southwesterly direction across Whitemans Pass to a point on the Kootenay River east of the Windermere mining district of British Columbia.

The region traversed by the section, which crosses the strike of the rocks, is broken into a series of longitudinal blocks, each shoved over its neighbor to the east and all more or less similarly tilted. The fossils secured show the thrust-faults between to be of large magnitude, but they coincide so largely with the valleys and with the strike and the local folding in their vicinity is so subordinate that the presence of faulting has not been recognized. Dawson is the only geologist who has made a previous crossing.

FURTHER LIGHT ON THE EARLIER STRATIGRAPHY OF THE CANADIAN CORDILLERA

BY LANCASTER D. BURLING

(*Abstract*)

This paper will deal with some of the more important of the discoveries of the 1917 field season.

New evidence was secured bearing on the question of the age relationships of the Lower Cambrian and Beltian rocks of British Columbia, Alberta, and Montana.

Careful search in the so-called "Castle Mountain" limestones at the head of Nyack Creek, Montana, yielded abundant casts of salt crystals, but no fossils. Their Siyeh age is almost unquestioned.

The Mount Robson region was visited and collections secured from many horizons, all the Cambrian and Ordovician formations above the lowest quartzitic sandstones being represented. Many doubtful points in the stratigraphy were cleared up—such, for example, as the true position of the Extinguisher ("Billings Butte") fauna, etcetera. Evidence secured would seem to indicate that while the *Callavia* and *Olenellus* zones are hardly to be separated as such in this region, *Callavia* does appear alone in the section first, later mingles with *Olenellus*, and finally disappears, leaving *Olenellus* alone.

The *Albertella* fauna was traced to the north, south, and east and further

collections secured from the horizon itself and from the rocks immediately above and below.

The Cambro-Devonian boundary was examined in numerous places, with the following results: On Roche Miette the Devonian has been described as separated from the Cambrian (in which the highest fossils now appear to be of Middle Cambrian age) by a series of beds tentatively referred to the Silurian. Further collections from these rocks appear to place them in the Devonian. In North Kootenay Pass the Middle Cambrian is separated from the Devonian by many hundreds of feet of apparently unfossiliferous strata. In the Beaverfoot Range near Golden the Devonian is absent, but the section includes several thousand feet of fossiliferous Upper Cambrian and Ordovician, up to and including the Richmond, east of Lake Minnewanka, and in the Sawback Range and upper Columbia Lake sections the Devonian rests on a series of beds whose fauna is comparable in many respects with that of the Ozarkian.

Many additional specimens of Triassic (?) fish were secured from the fish locality discovered in 1915 in the "Jurassic fault block" near Massive, west of Banff, Alberta.

Additional collections were made from the fossil locality discovered by Mr. Drysdale in the Laurie Metargillite near the Laurie mine, west of Glacier. These are limited to crinoid stems, but appear to indicate that the Laurie Metargillite is Upper Paleozoic in age.

Additional collections were secured by Mr. Bancroft and the writer from the general horizon in the Slocan series containing the doubtful fossils first discovered by Messrs. Drysdale and Bancroft in 1916. These have been examined by Mr. Kindle, who reports that they appear to be of Pennsylvanian age.

Professor Williston followed with a paper on the evolution of vertebræ, which was illustrated by numerous lantern slides and discussed by Doctor Merriam.

EVOLUTION OF VERTEBRÆ

BY S. W. WILLISTON

(*Abstract*)

The evolution of the holospondylous vertebra from the primitive embolomerous type is shown in the gradual decrease in size of the hypocentrum in the caudal vertebræ of the rhachitomous amphibians and the atlas of primitive reptiles to a wedge-shaped form not much larger than the dorsal intercentra of primitive reptiles and by the corresponding increase in size of the embolomerous disklike pleurocentrum into the body of the centrum of the primitive reptiles. It is evident that the rhachitomous amphibians have no immediate ancestral relationships with the reptiles, which must have sprung directly from the Embolomeri, probably in Mississippian times.

A second interesting paper on vertebrate paleontology, dealing with the paleopathology of vertebrates, was presented by Professor Williston for the author. This paper, which was likewise well illustrated with lantern slides, was discussed by Messrs. Williston, Merriam, and Grabau.

DISEASES OF THE MOSASAURS

BY ROY L. MOODIE

(*Abstract*)

During the Cretaceous, diseases of animals reached a maximum of development in the mosasaurs, dinosaurs, plesiosaurs, and their associates. The number of diseases known to have afflicted these animals are numerous and varied. Some of them are apparently identical with the diseases of animals and man today. Others have probably become extinct with the race of animals which they afflicted. The diseases of the mosasaurs may be taken as an example of the diseases of the Cretaceous. Their importance may be seen from the graph showing the general geological development of disease. The diseases which afflicted the mosasaurs, such as caries and pyorrhea, were common in geological time. Others, such as periostitis and necroses, are not so common, but are evident in the group. The paper will be illustrated by lantern slides showing examples of diseases of the mosasaurs.

(This paper is not to be published separately, but is a part of a monograph, under preparation, on "Paleopathology, a study of the antiquity of disease.")

A paper dealing with the paleobotanic side of paleontology was next presented by the author, who illustrated his remarks with a number of especially well preserved specimens.

REPORT ON A COLLECTION OF OLIGOCENE PLANT FOSSILS FROM MONTANA

BY O. E. JENNINGS

(*Abstract*)

A report on a collection of about two hundred leaf-impressions collected a few years ago by Mr. Earl Douglass, mostly from the White River beds near Missoula, Montana, and now in the Carnegie Museum.

The specimens are in a fine volcanic ash and are excellently preserved. There are fourteen species represented, five of these being conifers, the remainder being broad-leaved trees, with the exception of a fragment of a leaf of a sedge. The most abundant species is *Carpinus grandis* Unger, other common species being *Taxodium dubium* (Sternberg) Heer and a *Sequoia* closely related to *S. couttsiæ* Heer. Among notable species for North America are *Chamæcyparis ehrenswardi* Heer and *Thuyopsis gracilis* Heer.

There was then presented by the author and discussed by Doctor Matthew the following paper, illustrated by lantern slides:

NEW TILLODONT SKULL FROM THE HUERFANO BASIN, COLORADO

BY WALTER GRANGER

(*Abstract*)

Our knowledge of the skull and dentition of the large Middle Eocene Tillodonts has previously been derived almost wholly from a single specimen from

the Bridger Basin and preserved in the Marsh collection at Yale. While making a preliminary examination of the Huerfano Basin in 1916 the author secured a nearly perfect skull and jaws of one of these forms. This new specimen appears to be generically distinct from *Tillotherium* of Marsh and close to Leidy's *Trogosus*, a more primitive form from the Lower Bridger, in which the second pair of incisors in the lower jaw is still present. A study of the new Tillodont and associated material from the uppermost Huerfano leads to the belief that this horizon is slightly older than the Lower Bridger.

The following two papers on the invertebrate paleontology and stratigraphy of the West Coast were combined into a single paper by their author, who illustrated his discussion with diagrams. These papers were discussed by Messrs. Matthew, Grabau, Bassler, and Miss O'Connell.

MOLLUSCA OF THE CARRIZO CREEK BEDS AND THEIR CARIBBEAN AFFINITIES

BY ROY E. DICKERSON

(*Abstract*)

The fauna obtained from the Tertiary beds near Carrizo Creek, San Diego County, California, have yielded several unique echinoids and corals. The echinoids were described by Doctor Kew two years ago, but unfortunately he did not obtain any direct faunal connection with other Tertiary horizons. During the past year Dr. T. Wayland Vaughan described the corals obtained from these beds and he recognized the Caribbean affinities of these forms, and from this study concluded that the beds were Pliocene in age. The mollusca obtained by Kew, Buwalda, and English confirm Vaughan's conclusions concerning the Caribbean affinities of this interesting group of marine invertebrates. Several species appear to be identical with forms which are characteristic of the Gatun formations of Miocene age.

PROPOSED CORRELATION OF THE PACIFIC AND ATLANTIC EOCENE

BY ROY E. DICKERSON

(*Abstract*)

Identical species, similar stages of generic evolution, and the mutations of *Venericardia planicosta* all show a much stronger relationship of the Tejon group to the three lower formations of the Gulf province—the Midway, Wilcox, and Claiborne—than was suspected. Tejon time was long and was probably equivalent to Midway (in part, at least), Wilcox, and Claiborne eons. The Jackson may be represented by the upper portion of the rhyolitic tuffs, the clay rock of Turner.

This study confirms and modifies somewhat the former conclusion "that the Martinez is not only equivalent to a portion of the Midway, but represents a still earlier stage of the Eocene as well." The generic relations between the Tejon and Midway are so close that it seems probable that they are correlative, at least in part. Possibly the Martinez is the marine equivalent of the Puerco and Torrejon of New Mexico—that is, Paleocene.

	Pacific province	Gulf province
Tejon	*Siphonalia sutterensis* zone *Balanophyllia variabilis* zone	Claiborne
	Rimella simplex zone	Lower Claiborne Wilcox
	Turbinolia zone	Midway
Martinez	*Solen stantoni* zone *Trochocyathus zitteli* zone *Meretrix dalli* zone	Puerco and Torrejon (?)

New occurrences of glacial deposits in the Paleozoic rocks of southeastern Alaska were described in the next paper, which was presented for the author by the Secretary and illustrated by specimens.

PALEOZOIC GLACIATION IN SOUTHEASTERN ALASKA

BY EDWIN KIRK

(Abstract)

Paleozoic glaciation has not hitherto been recognized in Alaska. During the past field season a tillite of Silurian age was found in southeastern Alaska. Fairly conclusive evidence of Permo-Carboniferous glaciation was also secured. Conglomerates in the Devonian suggested the possibility of glacial beds in that period, but owing to lack of time and unfavorable weather conditions it was not possible to secure either positive or negative evidence as to their origin. The best exposures of the Silurian glacial beds seen were on Heceta Island, although good outcrops are to be found on the south shore of Kosciusko Island, about 15 miles to the north. Apparently the same beds occur along El Capitan passage between Kosciusko and Prince of Wales Islands. At the north end of Kuiu Island, some 125 miles to the north, a boulder bed holds the same stratigraphic position and I believe represents the same glacial deposit. Kosciusko and Heceta Islands, where the best Silurian glacial deposits are to be found, lie between 55° and 60° north latitude and 133° and 134° west longitude. These islands are situated on the west coast of Prince of Wales Island, toward the northern end.

The most favorable locality for an examination of the conglomerate is in the large bay about midway on the north shore of Heceta Island. The coast here is well protected from storms and there is a continuous outcrop of the limestone underlying the conglomerate, the conglomerate itself, and the overlying limestone. In places the conglomerate is well broken down by weathering, making the collection of pebbles and boulders an easy matter. As exposed, the beds outcrop along the shore between tide and levels and give an outcrop perhaps 2,000 to 3,000 feet in length.

The glacial conglomerate is under- and overlain by fossiliferous marine limestones. The succession of beds is clearly shown and unmistakable. The same relations can even more clearly be seen on the bold cliff at the east end of Heceta Island as to the upper limit of the conglomerate. The relations of the conglomerate to the underlying limestone are well shown on Kosciusko Island. The strata as a whole in this region are badly disturbed and, as is

the case throughout southeastern Alaska, contacts are very poorly shown, being, as a rule, indicated by an indentation of the shoreline and a depression running back into the timber. At present, therefore, although the relative positions of stratigraphic units are obvious, the character of the unconformity and the nature of the passage beds are poorly known.

The limestone series overlying the conglomerate carries a rich *Conchidium* fauna. In certain thin beds the rock is almost wholly made up of the brachiopods. This fauna appears to be identical with that of the Meade Point limestone of the Wrights and Kindle. The type exposure of the latter is at the northern end of Kuiu Island. At the base of the limestone at this locality is a boulder bed which I believe to be glacial in origin and to be correlated with the conglomerate of Heceta. The limestones below the conglomerate likewise carry a rich fauna consisting of pentameroids, corals, and gasteropods. The general aspect of both faunas seems to place them as approximately late Niagaran in age.

The conglomerate itself has a thickness of between 1,000 and 1,500 feet. In the main the conglomerate appears to consist of heterogeneous, unstratified, or poorly stratified material. Rarely lenticular bands of cross-bedded sandstone occur in the mass. These are clearly water laid and indicate current action.

The boulders in the tillite range in size up to two or three feet in length, as seen. The boulders consist of greenstone, graywacke, limestone, and various types of igneous rocks. Limestone boulders are scarce. All the boulders are smoothed and rounded. Facetted boulders are numerous and, given the proper type of rock, characteristic glacial scratches are common. The scratches show best on the fine-grained, dense greenstone. Limestone boulders and certain types of igneous rocks do not show them at all. The shoreline is strewn with these pebbles and boulders, which were undoubtedly derived from the conglomerate, as they are not to be found on the adjacent limestone shores. All the material collected was taken from the conglomerate itself, however. This is well broken down by weathering in some places, and the pebbles may be picked out with the fingers or tapped out with the hammer. When fresh the conglomerate, as a rule, is massive and exceedingly hard. The lantern slides will give a good idea as to the character of the conglomerate and nature of the crops as shown on the north shore of Heceta Island. Some of the boulders seen are entirely free and others are still partially embedded in the conglomerate.

The nature of the deposit is such as to suggest a till. The heterogeneous character of the boulders, both as regards size and material and the apparent lack of stratification in the main, points to a true till rather than a submarine bed of ice-transported glaciated material. Such evidence as is at hand indicates that the Heceta area was very near the shoreline and might easily have been land while the glacial material was being deposited. The whole Silurian section, which at its maximum farther north has a thickness of several thousand feet, thins out to the south and may prove to be absent at the south end of Prince of Wales Island.

In Pybus Bay, Admiralty Island, and on the Screen Islands off the west shore of Etolin Island are conglomerates strongly suggesting glacial material. In both cases these overlie high Carboniferous beds which have been corre-

lated by Girty with the Gschelian. Overlying the conglomerates are Middle Triassic beds. Where seen, the conglomerates had not weathered down and it was not possible to obtain loose boulders which might show scratches. Facetted boulders occur in the conglomerate, however. It will probably be found that this is a true glacial deposit and to be correlated with the conglomerate described by Cairnes near the Alaskan-Canadian boundary. A conglomerate similar to that described above underlies the Middle Triassic rocks of Dall Head, Gravina Island, and may prove of the same age and of similar character.

In the *Stringocephalus* limestone zone of the Middle Devonian small facetted pebbles up to 2½ inches in length are of fairly frequent occurrence at one locality on the west coast of Prince of Wales Island. In Freshwater Bay and in Port Frederick, which lie near the northern end of Chicagoff Island, some 250 miles to the north, conglomerates occur in the Middle Devonian. Rounded boulders up to 2 feet in diameter were seen. They are very unlike normal sedimentary conglomerates. Should the boulders in the Devonian prove glacial, a somewhat different origin would probably be postulated for the conglomerates themselves. These are thin, ranging in thickness up to 25 feet or so, and would be more easily explained perhaps as consisting of berg-borne material, though glacial in origin. Bottoms of a similar nature are even now to be found in the channels of southeastern Alaska.

Throughout the Paleozoic section in southeastern Alaska are vast thicknesses of volcanic material, tuffs, breccias, and flows. Considering the sediments as a whole, climatic conditions through the Paleozoic do not seem to have been very different from those of comparatively recent times and physical conditions may have been very nearly the same.

Some of the results of a monographic study of American Tertiary Cyclostome bryozoa were presented by the junior author in the following paper, which was illustrated by lantern slides and specimens and discussed by Doctor Grabau.

PRINCIPLES OF CLASSIFICATION OF CYCLOSTOME BRYOZOA

BY F. CANU AND R. S. BASSLER

(Abstract)

During the preparation of a monograph on American Tertiary bryozoa the authors extended their study of the Cyclostome bryozoa to the Cretaceous and recent forms in order to arrive at some definite data for the natural classification of this group. As the zooecial form is practically the same in all the Cyclostome bryozoa, it is impossible to base a classification on this as is done in the other groups of this class. Hitherto the classification of the Cyclostomata has been based almost entirely on the form of the colony or zoarium, although it has always been realized that this was a very unnatural basis. The present authors have found that the ovicell, the marsupium-like organ which is developed on Cyclostome bryozoa, affords a natural basis of classification and the families and genera group themselves according to the position and form of this organ.

There was then presented by the author a paper on the invertebrate paleontology of a new West Coast Tertiary formation, which was discussed by Doctor Dickerson, with replies by the author.

FAUNA OF THE MEGANOS GROUP

BY B. L. CLARK

An interesting fauna of fossil vertebrates was described in the following paper:

FOSSIL MAMMALS OF THE TIFFANY BEDS

BY W. D. MATTHEW AND WALTER GRANGER

(*Abstract*)

The Tiffany beds are a local phase at the base of the Wasatch north of the San Juan River, in southern Colorado. Fossil mammals were first found there by J. W. Gidley, on whose invitation Mr. Granger explored the deposit in 1916 for the American Museum. A small but interesting fauna was secured there, regarded as of uppermost Paleocene age, equivalent to the Clark Fork beds at the base of the Bighorn Wasatch. The fauna includes several new or little known genera of minute size, but of considerable paleontologic interest.

A paper by President Merriam on the Pliocene of Idaho was next on the program, but its presentation had to be omitted because the material illustrating it had not arrived.

FAUNA OF THE IDAHO TULARE PLIOCENE OF THE PACIFIC COAST REGION

BY J. C. MERRIAM

President Merriam then took the chair and called for a paper on vertebrate paleontology, of which the author presented an abstract. This was discussed by Doctor Matthew.

REVISION OF THE PSEUDOTAPIRS OF THE NORTH AMERICAN EOCENE

BY O. A. PETERSON

(*Abstract*)

This abstract is taken from the general report on the Vertebrata of the Upper Eocene of the Uinta Basin, Utah, ready for publication. In this review is included two new genera of pseudotapirs from the Upper Eocene. A new family and two new subfamilies are proposed.

A short paper on American fossil rhinoceroses was then presented by Doctor Matthew and discussed by Professor Merriam.

NOTES ON THE AMERICAN PLIOCENE RHINOCEROSES

BY W. D. MATTHEW

(*Abstract*)

Three genera of rhinoceroses occur in our Pliocene—*Aphelops*, *Peraceras*, and *Teleoceras*. They are distinct in the proportions of the skull, character of the horn-cores, upper and lower tusks, reduction of premolar teeth, hypsodonty of molar teeth, and by the proportions of limbs and feet. Although some or all may be derived from Old World ancestry, these genera are limited to North America and are distinct specializations from any of the various rhinoceros phyla of the Old World. They became extinct apparently before the end of the Pliocene.

New Upper Eocene mammals from Utah were then very briefly described by Mr. Peterson, who had prepared a much longer paper on the subject.

NEW ARTIODACTYLS FROM THE UPPER EOCENE OF THE UINTA BASIN, UTAH

BY O. A. PETERSON

(*Abstract*)

The paper is an abstract taken from the general report on the Vertebrata of the Upper Eocene of the Uinta Basin, Utah, now ready for publication.

A number of new genera of the subfamily Homacodontinæ are first taken up. Secondly, it gives a short description of an American *Anoplothere* and its relation to *Diplobune* of Europe. Thirdly, a brief description and complete restoration of a new oreodont from the Upper Eocene. And fourthly, a description of a new Eocene hypertragulid and a review of the relationship between the Uinta and the Oligocene genera of the Hypertragulidæ.

A paper on stratigraphy and invertebrate paleontology was next in order and was presented by the senior author. Discussed by Messrs. Dickerson and Grabau.

MARINE OLIGOCENE OF THE WEST COAST OF NORTH AMERICA

BY B. L. CLARK AND RALPH ARNOLD

(*Abstract*)

A general survey of the known data concerning the paleogeography, climatic conditions, and faunal relationships of the Oligocene as found in California, Oregon, Washington, and Vancouver Island.

The marine Mesozoic and Tertiary sediments of the West Coast were, for the most part, laid down in broad geosynclinal troughs, the axes of which paralleled that of the present ranges. The Tertiary sediments accumulated in these slowly sinking troughs to an enormous thickness. Roughly estimated, there are at least 40,000 feet of sediments of Tertiary age in the Coast Ranges; of this fully 10,000 feet belong to that period of time which is here referred

to the Oligocene. In Washington there was apparently a trough of deposition during the Oligocene time which extended from the Puget Sound district south between the Olympics and the Cascades into western Oregon. In California there was one large trough of deposition which extended from the region of Mount Diablo, middle California, to at least as far south as the San Emigdio Mountains, at the south end of the San Joaquin Valley, a distance north and south of over 200 miles. The axis of this trough, as indicated by the distribution of the organic shales, was in the eastern Coast Ranges. In the western Coast Ranges the Oligocene where present is represented by the shallow-water deposits; it is absent over large areas in this western field.

There are two general faunas known from the marine Oligocene deposits of the west coast. They very probably belong to two distinct epochs of deposition. The name San Lorenzo group is applied to the beds in which the lower fauna is found; the beds from which the upper fauna comes are referred to the Seattle group. The fauna of the Seattle group has not been determined in California for a certainty. The type section of the San Lorenzo is in the Santa Cruz Mountains of California. The fauna of the San Lorenzo group shows a closer relationship to that of the Tejon (Upper Eocene) than does that of the Seattle. On the other hand, the fauna of the Seattle group shows closer affinities to that of the Lower Miocene than does the San Lorenzo. These two Oligocene faunas show a much closer relationship to each other than does the one to the Eocene and the other to the Miocene.

In the absence of the author, Professor Merriam then read the final paper of the program.

THE QUESTION OF PALEOECOLOGY

BY F. E. CLEMENTS [1]

The following four papers of the program were read by title:

NOTE ON THE EVOLUTION OF THE FEMORAL TROCHANTERS IN REPTILES AND MAMMALS

BY WILLIAM H. GREGORY

CARBONIFEROUS SPECIES OF "ZAPHRENTIS"

BY G. H. CHADWICK

EXTINCT VERTEBRATE FAUNAS FROM THE BADLANDS OF BAUTISTA CREEK AND SAN TIMOTEO CANYON OF SOUTHERN CALIFORNIA

BY CHILDS FRICK

NOTES ON EIFEL BRACHIOPODS

BY G. H. CHADWICK

On motion, at 6 p. m. the Society adjourned.

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[1] Introduced by J. C. Merriam.

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Willis T. Lee, U. S. Geological Survey, Washington, D. C.
Frederick B. Loomis, Amherst College, Amherst, Mass.
Richard S. Lull, Yale University, New Haven, Conn.
D. D. Luther, Naples, N. Y.
Victor W. Lyon, Jeffersonville, Ind.
Thomas H. McBride, University of Iowa, Iowa City, Iowa.
J. H. McGregor, Columbia University, New York City.
Wendell C. Mansfield, U. S. Geological Survey, Washington, D. C.
Clara G. Mark, Department of Geology, Ohio State University, Columbus, Ohio
Bruce Martin, Waukena, Tulare County, Cal.
K. F. Mather, Queens University, Kingston, Ontario.
W. D. Matthew, American Museum of Natural History, New York City.
T. Poole Maynard, 1622 D. Hunt Building, Atlanta, Ga.
Maurice G. Mehl, University of Oklahoma, Norman, Okla.
John C. Merriam, University of California, Berkeley, Cal.
Rector D. Mesler, U. S. Geological Survey, Washington, D. C.
Roy L. Moodie, University of Illinois, Congress and Honore Sts., Chicago, Ill.
Clarence L. Moody, University of California, Berkeley, Cal.
W. O. Moody, 1829 Berryman Street, Berkeley, Cal.
Charles C. Mook, American Museum of Natural History, New York City.
R. C. Moore, Department of Geology, University of Kansas, Lawrence, Kans.
Robert B. Moran, 632 Title Insurance Building, Los Angeles, Cal.
William C. Morse, Department of Geology and Geography, Washington University, St. Louis, Mo.
James E. Narraway, Department of Justice, Ottawa, Canada.
Jorgen O. Nomland, University of California, Berkeley, Cal.
Marjorie O'Connell, Columbia University, New York City.
Henry Fairfield Osborn, American Museum of Natural History, New York City.
R. W. Pack, U. S. Geological Survey, Washington, D. C.
Earl L. Packard, Department of Geology, University of Oregon, Eugene, Oreg.
William A. Parks, University of Toronto, Toronto, Canada.
William Patten, Dartmouth College, Hanover, N. H.
O. A. Peterson, Carnegie Museum, Pittsburgh, Pa.
Alexander Petrunkevitch, 266 Livingston Street, New Haven, Conn.
William A. Price, Jr., West Virginia University, Morgantown, W. Va.
Percy E. Raymond, Museum of Comparative Zoology, Cambridge, Mass.
Chester A. Reeds, American Museum of Natural History, New York City.
John B. Reeside, Jr., U. S. Geological Survey, Washington, D. C.
Charles E. Resser, U. S. National Museum, Washington, D. C.
E. S. Riggs, Field Museum of Natural History, Chicago, Ill.
Wilbur I. Robinson, Vassar College, Poughkeepsie, New York.

Paul V. Roundy, U. S. Geological Survey, Washington, D. C.
Robert R. Rowley, Louisiana, Mo.
Rudolf Ruedemann, Education Building, Albany, N. Y.
Frederick W. Sardeson, 414 Harvard Street, Minneapolis, Minn.
Clifton J. Sarle, University of Arizona, Tucson, Arizona.
Thomas E. Savage, University of Illinois, Urbana, Ill.
William H. Shideler, Miami University, Oxford, Ohio.
Charles Schuchert, Yale University, New Haven, Conn.
William B. Scott, Princeton University, Princeton, N. J.
Elias H. Sellards, Tallahassee, Fla.
Henry W. Shimer, Massachusetts Institute of Technology, Boston, Mass.
William J. Sinclair, Princeton University, Princeton, N. J.
Burnett Smith, Syracuse University, Syracuse, N. Y.
Frank Springer, U. S. National Museum, Washington, D. C.
T. W. Stanton, U. S. Geological Survey, Washington, D. C.
Clinton R. Stauffer, University of Minnesota, Minneapolis, Minn.
L. W. Stephenson, U. S. Geological Survey, Washington, D. C.
Charles H. Sternberg, Lawrence, Kans.
Chester Stock, 492 Seventh Street, San Francisco, Cal.
Reginald C. Stover, Standard Oil Building, San Francisco, Cal.
Charles K. Swartz, Johns Hopkins University, Baltimore, Md.
Mignon Talbot, Mt. Holyoke College, South Hadley, Mass.
Edgar E. Teller, 305 Endicott Street, Buffalo, N. Y.
A. O. Thomas, Department of Geology, University of Iowa, Iowa City, Iowa.
Albert Thompson, American Museum of Natural History, New York City.
Edward L. Troxell, Dept. of Geology, Univ. of Michigan, Ann Arbor, Mich.
William H. Twenhofel, University of Wisconsin, Madison, Wis.
M. W. Twitchell, Geological Survey of New Jersey, Trenton, N. J.
Edward O. Ulrich, U. S. Geological Survey, Washington, D. C.
Claude E. Unger, Pottsville, Pa.
Jacob Van Deloo, Education Building, Albany, N. Y.
Gilbert Van Ingen, Princeton University, Princeton, N. J.
Francis M. Van Tuyl, University of Illinois, Urbana, Ill.
T. Wayland Vaughan, U. S. Geological Survey, Washington, D. C.
Anthony W. Vogdes, 2425 First Street, San Diego, Cal.
Charles D. Walcott, Smithsonian Institution, Washington, D. C.
Clarence A. Waring, 580 McAllister Street, San Francisco, Cal.
Charles F. Weaver, University of Washington, Seattle, Wash.
Stuart Weller, University of Chicago, Chicago, Ill.
David White, U. S. Geological Survey, Washington, D. C.
Edward J. Whittaker, Geological Survey of Canada, Ottawa, Canada.
G. R. Wieland, Yale University, New Haven, Conn.
Henry S. Williams, Cornell University, Ithaca, N. Y.
Merton Y. Williams, Geological Survey of Canada, Ottawa, Canada.
Samuel W. Williston, University of Chicago, Chicago, Ill.
Alice E. Wilson, Victoria Memorial Museum, Ottawa, Canada.
Herrick E. Wilson, U. S. National Museum, Washington, D. C.
William J. Wilson, Geological Survey of Canada, Ottawa, Canada.

Elvira Wood, Museum of Comparative Zoology, Cambridge, Mass.
Wendell P. Woodring, Dept. of Geology, Johns Hopkins Univ., Baltimore, Md

CORRESPONDENT DECEASED

E. Koken, died November 24, 1912.

MEMBERS DECEASED

Samuel Calvin, died April 17, 1911.
William B. Clark, died July 27, 1917.
Orville A. Derby, died November 27, 1915.
William M. Fontaine, died April 30, 1913.
Theodore M. Gill, died September 25, 1914.
Robert H. Gordon, died May 10, 1910.
J. C. Hawver, died May 15, 1914.
C. S. Prosser, died September 11, 1916.
Henry M. Seely, died May 4, 1917.

MEMBERS-ELECT

F. E. Clements, Carnegie Institution, Washington, D. C.
Lee Raymond Dice, University of Montana, Missoula, Mont.
Childs Frick, Santa Barbara, Cal.
Eugene Schofield Heath, Botany Hall, Univ. of California, Berkeley, Cal.
Remington Kellogg, 2212A Union, Berkeley, Cal.
Wayne Frederick Loel, Department of Geology and Mining, Standford University, Palo Alto, Cal.
Eula D. McEwan, U. S. National Museum, Washington, D. C.
Ida Carter Oldroyd, College Terrace, Palo Alto, Cal.
Carroll Marshall Wagner, 2604 Etna Street, Berkeley, Cal.

Minutes of the Eighth Annual Meeting of the Pacific Coast Section of the Paleontological Society

By Chester Stock, *Secretary*

The eighth annual meeting of the Pacific Coast Section of the Paleontological Society was held at Stanford University on April 6 and 7, 1917, the Society participating in the second annual meeting of the Pacific Division of the American Association for the Advancement of Science. A short, joint session with the Geological Society and the Seismological Society was held on April 6, at which time Prof. John C. Merriam spoke on preparedness. At the conclusion of Professor Merriam's address, the meeting adjourned, and the Paleontological Society was called to order in separate session by Dr. J. P. Buwalda at 3.15 o'clock, in room 360, Mineralogy Building.

ELECTION OF OFFICERS

The following officers were elected for the ensuing year:

President, Bruce L. Clark, University of California.
Vice-President, Chester Stock, University of California.
Secretary-Treasurer, Chester Stock, University of California.

PRESENTATION OF PAPERS

The following papers were then read:

SYSTEMATIC POSITION OF THE DIRE WOLVES OF THE AMERICAN PLEISTOCENE

BY J. C. MERRIAM

NOTE ON THE OCCURRENCE OF A MAMMALIAN JAW, PRESUMABLY FROM THE TRUCKEE BEDS OF WESTERN NEVADA

BY J. C. JONES

(*Abstract*)

During the summer of 1916 a small mammalian jaw came into the possession of the University of Nevada that had been found in digging a shallow well near Washoe City, Nevada. While the jaw was found in the recent alluvium at present covering the greater part of the floor of Washoe Valley, yet the only sedimentary beds from which it could have been eroded are similar in composition to the Truckee beds and believed to be of the same age.

Read by title.

PINNIPEDS FROM MIOCENE AND PLEISTOCENE DEPOSITS OF CALIFORNIA

BY REMINGTON KELLOGG

(*Abstract*)

A new genus and species of sea-lion from the Temblor, together with seal remains from the Santa Margarita and San Pedro, are described. The discussion includes a résumé of current theories regarding origin of the Pinnipedia.

PUMA-LIKE CATS OF RANCHO LA BREA

BY J. C. MERRIAM

GRAVIGRADE EDENTATES IN LATER TERTIARY DEPOSITS OF NORTH AMERICA

BY CHESTER STOCK

(*Abstract*)

A review of occurrence of gravigrade edentates in Miocene and Pliocene deposits of North America. Particular attention is directed to recent discoveries

of ground-sloth remains in the Rattlesnake Lower Pliocene of eastern Oregon and in Lower Pliocene beds exposed along San Pablo Bay, California.

RELATIONSHIPS OF RECENT AND FOSSIL INVERTEBRATE FAUNAS ON THE WEST SIDE OF THE ISTHMUS OF PANAMA TO THOSE ON THE EAST SIDE

BY IDA S. OLDROYD

(*Abstract*)

The range of various invertebrate species of the marine provinces to the west and east of the Isthmus of Panama is discussed, and attention directed to forms common to both sides of the isthmus. The report includes a statement concerning origin of certain of these species from a common stock, as well as observations on former trans-Panamic marine connections.

TROPITIDÆ OF THE UPPER TRIASSIC OF CALIFORNIA

BY J. P. SMITH

(*Abstract*)

A series of species of Tropites and near relatives are exhibited, showing evolution of the group and forming the basis for a discussion of species-forming. These are species in the making and give good examples of series diverging but little from each other and from the common ancester. A discussion is also given of the correlation of the *Tropites subbullatus* zone and the classification of the Upper Triassic of California.

FAUNA OF THE IDAHO FORMATION

BY JOHN C. MERRIAM

(*Abstract*)

A very extensive series of sediments exposed in the valley of the Snake River, in southwestern Idaho, described by Cope as the Idaho formation, has been carefully studied and described by Lindgren. From this formation a mammalian fauna secured by Lindgren has been listed by Lucas and referred to the Pliocene.

The known list of mammals from the Idaho includes a number of forms which approach very closely in their stage of evolution to the Pleistocene of western North America, but differ specifically from all Pleistocene species. Such differences as appear are mainly in the direction of primitiveness. A number of other forms found in the Idaho fauna are distinctly of a Pliocene type. As nearly as can be judged, the mammalian fauna of the Idaho represents a Pliocene stage later than any other Pliocene fauna of the Pacific Coast and Great Basin regions, with possible exception of the Tulare Pliocene occurrence on the western border of the San Joaquin Valley.

OCCURRENCE OF A MARINE MIDDLE TERTIARY FAUNA ON THE WESTERN BORDER OF THE MOJAVE DESERT AREA

BY WALLACE GORDON

Read by J. C. Merriam.

FAUNA OF THE BAUTISTA CREEK BADLANDS

BY CHILDS FRICK

(*Abstract*)

During the fall of 1916 the posterior portion of a lower jaw of a fossil horse from the Bautista Creek badlands, near Hemet, California, came into the hands of Dr. J. C. Merriam through the kindness of Mr. J. C. Blackburn. Several weeks of systematic collecting at this locality has resulted in the gathering of other well preserved horse remains, some cervid material, including parts of the dentition, skull, and skeleton, as well as fragmentary evidence of an antelope smaller than *Capromeryx minor*, and of a small ground sloth.

The dentition of the horse is of primitive character and apparently indicates a new form. The other species likewise appear to be new, and all probably represent a new or imperfectly known stage in the faunal sequence from the late Pliocene to the early Pleistocene.

This fauna is particularly interesting in its geographic position between the marine beds of the Pacific and those of the Gulf.

OCCURRENCE OF THE SIPHONALIA SUTTERENSIS ZONE, THE UPPERMOST TEJON HORIZON IN THE OUTER COAST RANGES OF CALIFORNIA

BY ROY E. DICKERSON

(*Abstract*)

The uppermost horizon of the Tejon Eocene of California, the *Siphonalia sutterensis* zone, was described from the Eocene of Marysville Buttes and later recognized as occurring at Oroville, beneath the basalt of Oroville, South Table Mountain, at Ione, on the western flanks of the Sierra Nevada, and at Merced Falls. In the study of the Mount Diablo region, the Coalinga District, and the southern end of San Joaquin Valley, at the type locality of the Tejon group and at San Diego, this upper horizon was not recognized. The zone was placed as an uppermost phase on the basis of stage of evolution and its close connection with the *Balanophylia variabilis* zone of the Mount Diablo region. A year ago Mr. Reginald Stoner discovered a locality in the Santa Susana Mountains, on Aliso Canyon, of Devil Creek, just beneath Miocene strata. The fossils from this locality represent a lower phase of the *Siphonalia sutterensis* zone and the fauna is essentially the same as the *Siphonalia sutterensis* zone of the Roseburg quadrangle, on Little River, near the confluence with the Umpqua. In the Simi Hills, a few miles away from the locality discovered by Mr. Stoner, the *Rimella simplex* zone of the Middle Tejon stage occurs. The general absence of this zone throughout most of the Coast Range region is probably due to extensive erosion during the interval between Upper Eocene and Oligocene time.

At the conclusion of the reading of papers the meeting adjourned and the members of the Paleontological Society attended a dinner of the Le Conte Club, at the Stanford Union.

On Saturday, April 7, at 10.45, the meeting was called to order by Dr. C. E. Weaver. The following papers were presented:

CRETACEOUS AND TERTIARY STRATIGRAPHY OF THE WESTERN END OF THE SANTA INEZ MOUNTAINS, SANTA BARBARA COUNTY, CALIFORNIA

BY H. J. HAWLEY

(*Abstract*)

The western end of the Santa Inez Mountains is made up wholly of sedimentaries of Cretaceous and Tertiary age. The Cretaceous is represented by Chico sandstones, overlain unconformably by Tertiary sediments. The Tejon is the local representative of the Eocene period, and the fauna of this series shows a remarkable similarity to the fauna from the type Tejon. Lower Miocene, which may be divided into Vaqueros and Monterey, represents the latest period of deposition in this regino.

GEOLOGIC RANGE AND EVOLUTION OF THE MORE IMPORTANT PACIFIC COAST ECHINOIDS

BY W. S. W. KEW

(*Abstract*)

Geologic ranges of the more important echinoid genera of the Pacific coast are as follows: *Cidaris*, Eocene, with exception of one species in the Oligocene; *Strongylocentrotus*, Pliocene to Recent; *Scutella*, Upper Eocene to Pliocene, with greatest development in the Lower Miocene; *Dendraster*, dominant in the Pliocene and continuing to the Recent; *Astrodapsis*, confined to the Upper Miocene and Lower Pliocene.

Scutella, *Astrodapsis*, and *Dendraster* serve best to illustrate the lines of descent of echinoids on the Pacific coast. *Scutella* evolves along two main lines, that of the *S. coosensis*–*S. norrisi* group and that of the *S. merriami*–*S. blancoensis* group. *Astrodapsis*, derived from the *Scutellas*, acquires the characters of elevated petals and grooved interambulactral areas, which become more pronounced until the specialized *A. major* and *A. arnoldi* stages are reached. Following these stages the genus suddenly becomes extinct. *Dendraster*, also originating from the *Scutellas*, passes from the *D. gibbsi* type, with more or less thickened test and eccentric apical system, to the thin test and extreme apical eccentricity of *D. ashleyi* (Arnold), and finally to the recent *D. excentricus* (Eschscholtz), with a less eccentric apical system.

EVIDENCE IN SAN GORGONIO PASS, RIVERSIDE COUNTY, OF A LATE PLIOCENE EXTENSION OF THE GULF OF LOWER CALIFORNIA

BY F. E. VAUGHAN

(*Abstract*)

A small invertebrate fauna was collected in San Gorgonio Pass, 3 miles east of Millard Canyon. Several forms from this locality are the same as

species found by W. S. W. Kew at Carrizo Creek. The beds occurring at the latter locality are considered by T. W. Vaughan as not older than Lower Pliocene.

VAQUEROS FORMATION IN CALIFORNIA

BY W. F. LOEL

(*Abstract*)

The horizon markers and principal features show this division of the Lower Miocene to be a distinct and true formation, both faunally and lithologically.

TERTIARY AND PLEISTOCENE FORMATIONS OF THE NORTH COAST OF PERU, SOUTH AMERICA

BY G. C. GESTER

(*Abstract*)

The Tertiary formations of the north coast of Peru are similar in many respects to the Tertiary formations of the west coast of North America. A comparison of the faunas shows many closely related species. An interesting feature of the north Peruvian coast is the elevated tableland, or "tablaza," which extends for several miles inland from the coast. The "tablaza beds" are richly fossiliferous and probably belong to the Pleistocene period.

SYMPOSIUM ON CORRELATION OF OLIGOCENE FAUNAS AND FORMATIONS OF THE PACIFIC COAST

BY C. E. WEAVER, R. E. DICKERSON, AND B. L. CLARK

PALEOGEOGRAPHY OF THE OLIGOCENE OF WASHINGTON

BY CHARLES E. WEAVER

(*Abstract*)

Two Oligocene embayments occur in Washington. The northern embayment occupied approximately the area between the Olympic Mountains and Vancouver Island and extended into the Puget Sound Basin as far south as Seattle. The southern embayment existed in the present region of Gray's Harbor and extended as far south as the Cowlitz Valley, in the northern part of Cowlitz County. In the northern embayment there were deposited approximately 14,000 feet of sandstone and shale. In the southern embayment the deposits are 4,000 feet in thickness. The basal faunas in the southern embayment, as represented at Oakville, are the same as the basal faunas in the northern embayment at Port Discovery Bay, near Port Townsend, and also the basal beds on the south shore of Vancouver Island, which have been described as the Sooke Beds. In both the northern and southern embayments the strata above the Sooke Beds contain a fauna of subtropical character which has been designated the *Molopophorous lincolnensis* zone, the type locality of which is at Lincoln Creek, in Thurston County. In the northern embayment the Upper Oligocene

beds contain a colder water fauna, which has been designated as the *Acila gettysburgensis* zone. This fauna is absent in the southern embayment.

PALEONTOLOGY AND STRATIGRAPHY OF THE PORTER DIVISION OF THE OLIGOCENE IN WASHINGTON

BY KATHERINE E. VAN WINCKLE

(*Abstract*)

The report embodies the results of stratigraphic and faunal studies of the Porter division of the Oligocene of Washington at the type locality on Porter Creek. The formation consists predominantly of shaly sandstones and sandy shales having a thickness of 1,200 feet. These beds rest unconformably on Tejon basalts. From the lower portion of the section a marine invertebrate fauna of 20 species was obtained, while from the upper beds 30 species were secured. Twelve species occurring in the lower beds are common to those in the upper. The fauna at Porter has a closer similarity to that at Lincoln Creek than it has to the Blakely fauna at Restoration Point. It is possible that the beds at Porter can be correlated with those exposed at Lincoln Creek.

Read by C. E. Weaver.

FAUNAL ZONES OF THE OLIGOCENE

BY B. L. CLARK

CLIMATE AND ITS INFLUENCE ON OLIGOCENE FAUNAS OF THE PACIFIC COAST

BY ROY E. DICKERSON

At the conclusion of the reading of the papers the meeting adjourned

REGISTER OF MEMBERS AND VISITORS AT STANFORD MEETING, 1917

E. M. BUTTERWORTH
J. P. BUWALDA
B. L. CLARK
R. E. DICKERSON
CHILDS FRICK
MRS. CHILDS FRICK
G. C. GESTER
H. GESTER
H. J. HAWLEY
E. S. HEATH
A. R. KELLOGG
W. S. W. KEW
W. F. LOEL
J. C. MERRIAM
J. O. NOMLAND
IDA OLDROYD
K. H. SCHILLING
J. P. SMITH
W. S. T. SMITH
CHESTER STOCK
C. M. WAGNER
C. E. WEAVER

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 29, PP. 167-186 MARCH 31, 1918

EXPERIMENT IN GEOLOGY [1]

PRESIDENTIAL ADDRESS BY FRANK DAWSON ADAMS

(Read before the Society December 27, 1917)

CONTENTS

Early geological Literature

One of the most fascinating studies which can engage the attention of a geologist is the literature of his science of a century or so ago. Some of the problems then discussed have long since received their answers and been laid aside; others, like ghosts, refuse to be laid and are still with us. But in all cases the point of view is so different from that of the present time, and in many cases the arguments adduced are so quaint and curious, that the picture of the geological science of those early days is one of peculiar interest. The theological influence of the cosmogonist permeates much of the writings of this early time, and there are scores of treatises on the constitution and history of the earth, in which the authors have drawn their material in part from a nodding acquaintance with certain of the salient phenomena of nature, but chiefly from an extended study of Holy Writ and the works of the church fathers, rounded out by considerations as to the manner in which they themselves would have created the world had they been called on to bend their energies to this important task. Among the works of this class, one of the best known is by Burnet, which appeared in 1697 and is entitled "The Sacred Theory of the Earth, containing an account of the Origin of the Earth and of all the general changes which it hath already undergone or is to undergo till the Consummation of all Things."

[1] Manuscript received by the Secretary of the Society December 27, 1917.

Some of the ideas presented in this early literature are not only quaint, but rather striking in their ancient dress; but when more closely examined we come to recognize in them certain well known friends. For example, there is the theory, frequently mentioned, of the "vegetability of minerals." Are the minerals in the earth's crust found in the state in which they were originally created or are they continually growing? Such is the question put forward by John Webster in his "Metallographa, or an History of Metals," which was published in London in the year 1670 and in which the thesis of the growth or "vegetability" of minerals is sustained at length under four heads.

It is interesting to trace the line of argument, which in his own words is as follows:

"It appears in Genesis that plants were not created perfect at first, but only in their 'seminaries,' for Moses, chapter 2, gives as a reason why plants were not come forth of the earth, because there had as yet neither any rain fallen nor any dew ascended from the earth whereby they might be produced or nourished. The like we may judge of minerals, that they were not at first created perfect, but disposed of in such sort that they should perpetuate themselves in their several kinds. And to the same purpose the profound Sendivoglus saith: 'And what prerogative have vegetables above metals that God should put feed into them and undeservedly exclude these. Are not metals of the same dignity with God as trees are? And, further, whosoever hath diligently considered the manner how most metals do lie in their wombs or beds in the bare rock must necessarily conclude that they could never have penetrated the clefts, chinks, and porous places in such hard bodies unless they were in *principiis solutis* either in water or vapours and steams, and after concocted and matured into several forms of metals, which is an analogous, if not an univocal, generation.' "

A final reason, though, as the author remarks:

"Some may account it light, yet I hold it to be very cogent, and so will all persons who understand the philosopher's grand secret, is that Nature's ultimate labor is in time to bring all metals to the perfection of gold, which she would accomplish if they were not unripe and untimely taken forth from the bowels of the earth."

The philosophers merely seek by their art to accelerate the work of Nature in bringing about the passage from the base metal to gold in their laboratories.

"So it is clear that if metals have not a kind of vegetability in them, then is the art of the transformation of metals false and all the grounds of the more abstruse philosophy without verity."

Then we have cases cited where minerals have been found growing in nature at the present time—for example, niter in earth which has been

allowed to stand a year after a previous treatment for extraction of the substance, iron ore in lakes in several places, flakes of metallic silver in old pit timbers in certain mines—in fact, in Joachimthal silver has been seen to grow out of the stones of the mine—

"in the manner and fashion of grass, as from a root in the length of a finger, very pleasant to behold. In places this silver doth embrace the stone in most tender leaves, plates, and spangles. It sometimes beareth the shape of hairs; sometimes of little twigs. Sometimes it beareth the shape of a tree."

And so we pass on naturally to the "golden tree," to which frequent reference is made by ancient writers and which is described by Peter Martyr in the following terms:

"They have found by experience that the vein of gold is a living tree, and that the same by all ways spreadeth and springeth from the root, by the soft pores and passages of the earth, putteth forth branches, even to the uppermost part of the earth, and ceaseth not until it discover itself unto the open air; at which time it showeth forth certain beautiful colors in the stead of flowers, round stones of golden earth in the stead of fruits, and thin plates in stead of leaves. These are they which are dispersed throughout the whole island [he is speaking of Hispaniola] by the course of the rivers, eruptions of the springs out of the mountains, and violent falls of the floods; for they think such grains are not engendered where they are gathered, especially on the dry land, but otherwise in the rivers. They say that the root of the golden tree extendeth to the center of the earth, and there taketh nourishment of increase; for the deeper that they dig they find the trunks thereof to be so much the greater, as far as they may follow it, for abundance of water springing in the mountains. Of the branches of this tree they find some as small as a thread and others as big as a man's finger, according to the largeness or straightness of the rifts and clefts. They have sometimes chanced on whole caves, sustained and born up, as it were, with golden pillars, and this in the ways by which the branches ascend: the which being filled with the substance of the trunk creeping from beneath the branch, maketh itself way by which it may pass out. It is oftentimes divided by encountering with some kind of hard stone; yet it is in other clifts nourished by the exhalations and virtue of the root."

Modern experimental Methods

Thus we have in an antique dress the modern "theory of ascension," as applied to the origin of mineral veins, and of the now well known fact of the derivation of placer deposits from auriferous veins.

In the years which have passed since the childhood of geological science such a thorough knowledge of the structure, of at least the superficial portion of the earth's crust, has been obtained that geological science in many fields has developed that power of prediction which by some has been cited as the characteristic of a true science—so much so that the

geologist now precedes the engineer in all great mining operations where these are efficiently conducted, and could with great advantage to the public purse and public welfare have preceded him in many great civil-engineering enterprises.

This high attainment in our scientific knowledge of the earth's crust has been achieved by close and long continued observation carried on by many men through many years.

Observation is the great basis and foundation stone of the science of geology; but as a companion and helper on this delightful, but sometimes toilsome, path—and more especially in the later years—observation has had the support of experiment, which while of distinctly subordinate and collateral value as compared with observation, has nevertheless rendered many important services in the development of geological knowledge.

Experiment in geology is in almost all cases really experimentation in physics or chemistry applied to geological problems, and we find at the very outset that here the experimental method is at a disadvantage, in that the scale on which the earth is constructed is so immense, and the forces at work so enormous, and the time concerned so vast, that in many cases the reproduction of the conditions which obtain in nature almost seems beyond our reach. This, however, is by no means always the case, and with the ever increasing facilities at our command experiment is being carried ever farther forward into regions of geological study which in former times seemed to be forever inaccessible to it.

We are said to experiment when we subject materials to varying conditions of pressure, temperature, chemical action, etcetera, and record the changes observed. It is thus possible to ascertain which of these conditions is the essential factor in developing the geological phenomena under observation.

Furthermore, if it be found that a chemical change or mechanical movement which takes place at the ordinary temperature with extreme slowness is expedited by an increase in temperature, it is often possible by increasing temperature to carry out in a reasonable time an experiment which under the exact conditions which obtain in nature might require years, or even decades or centuries, to complete. While, therefore, many great regions of geological investigation still remain closed to the experimental method, numerous other wide fields of geological study are open to experiment and will probably continue to enlarge as time goes on.

This was clearly shown when the Governing Board of the Carnegie Institution of Washington had submitted to it the proposal for the estab-

lishment of a geophysical laboratory to be devoted to advanced work in experimental geology. There was a doubt at first in the minds of some members of the Board as to whether this field was sufficiently large to warrant the very large expenditure which would be required to build, equip, and maintain such an institution. A group of geologists were accordingly asked to consider the question and to submit a list of geological problems which in their opinion were susceptible of solution by the experimental method. This was done, and the list which was drawn up may be found in the "Year Book of the Carnegie Institution" for 1903. The mere enumeration of these problems showed the field to be so extensive that the Board at once decided to establish the laboratory, which with its brilliant staff and magnificent equipment has now come to be the foremost center of geological experimental research in the world.

The importance of the experimental method came to be generally recognized in the world of science through the writings of Francis Bacon, who set forth its transcendent value as a path for attaining "the knowledge of causes and secret motions of things." His plan for the investigation of nature, outlined in his "New Atlantis," which went through ten editions between 1627 and 1670, suggested the establishment of a "College for the Promoting of Physico-Mathematicall Experimentall Learning," what we would now call a university of research, endowed by the State, which eventually took form in the Royal Society of London, founded in 1662, receiving grants from the State for the prosecution of scientific research and acting in an advisory capacity to the government in questions requiring scientific knowledge. It is thus the oldest scientific society in the world, and it is interesting here to note that Benjamin Franklin was elected a Fellow of this Society in 1756. The inscription on his portrait which hangs in the Society's rooms at Burlington House runs:

"Benjamin Franklin, LL. D., F. R. S. (1706-1790)—American, Philosopher, and Statesman. In 1757 came to England as agent for Pennsylvania. Elected F. R. S. 1756 and contributed papers on electrical subjects to the Philosophical Transactions. Copley Medallist, 1753."

The Growth of experimental Science

It is very interesting to follow the growth of experimental science as seen in the long series of papers which have appeared in the successive volumes of the Philosophical Transactions of the Royal Society from the early days to the present time. Of these, however, comparatively few deal with strictly geological problems; but in the abstract of a paper by

Doctor Lister, entitled "On the cause of earthquakes and volcanoes," which appeared in Volume II, published in 1705, the author presents a most interesting discussion of these phenomena concerning which we are still speculating, not, however, it is to be hoped, without making some very substantial advances toward their true solution. "I have elsewhere shown," says Doctor Lister, "that the breath of pyrites is *sulphur ex tota substantia.* Again, that the material which is the cause of thunder and lightning and of earthquakes is one and the same, namely, the inflammable breath of pyrites, the difference being that one is fired in the air and the other underground." He then goes on to give his reasons, which time will not permit us here to reproduce, but which are most ingenious, and then continues: "We with great probability believe volcanoes to be mountains made in great part of pyrites by the great quantities of sulphur therein sublimed and the application of the lodestone to the ejected cinder." He considers that the mountains were probably "kindled shortly after creation" and by the spontaneous ignition of this mineral.

Iron pyrites giving off sulphur, as it does when heated, was looked on askance, as in some way connected with diabolical manifestations in nature. The author of "A Theory and History of Earthquakes," published in London in 1753, writes:

> "This *dreadful* mineral is found in England as well as in other places more subject to earthquakes, but in smaller quantities and generally containing less of the sulphur, and this may be a principal reason why our earthquakes have been hitherto very slight and comparatively few."

This relation of volcanic phenomena to sulphurous minerals had further support in the general opinion coming down through the centuries from the time of the Greeks, or even earlier, that the center of the earth was a place of everlasting fire, serving, as one ancient writer puts it, as "an eternal jakes or prison, destined for the punishment of the damned." The brimstone always associated in the popular mind with this place of plutonic punishment related itself admirably to the sulphurous exhalations from craters at the surface and to the occurrence of pyrites in the intervening strata, although the conception gave rise at times to certain curious intellectual difficulties.

Thus, in referring to the vent at Vulcano, in the Phlegrean Fields, the writer just quoted asks:

> "If this be hell, what a desperate end made that unhappy German who not long since slipped into these furnaces, or what had his poor horse committed that fell in with him that he should be damned, or at least retained, in purgatory?"

An experiment is described by several writers of this period which was considered by them to demonstrate that it was to the presence of great deposits of self-igniting sulphurous minerals in the earth's crust we must look for the cause of volcanic action. The experiment consists in mixing several pounds of iron filings in equal parts with sulphur, moistening the mass with water, and burying it to a depth of a few feet in the ground. Presently, we are informed, it begins to heat, and in a few hours the earth will begin to tremble and crack; fire and smoke will burst through, and it is only necessary to postulate a sufficient quantity of this mixture to produce a true Etna. "This experiment, continues one author, sufficiently explains and illustrates the cause of earthquakes, volcanoes, and all fiery eruptions from the earth, for nothing more is requisite than iron, vitriolic acid, and water; and iron," he continues, "is generally found accompanied by sulphur."

Such early experiments, while they have no real importance or value, may be taken as an evidence of a growing interest in the experimental method and as the forerunners of more important and serious work which was to follow in later years.

It was the well known controversy between the Neptunists and the Plutonists that afforded the first striking example of the importance of experiment in geology.

The Neptunists held that fire, while liquefying substances by fusion, could never produce crystalline bodies, since the fused mass in cooling was always glassy in character. A crystalline structure could, according to their tenets, be produced only by deposition from solution. They held, therefore, that crystalline rocks—as, for example, basalt—could not have been produced by fire, but must have originated by deposition from water.

They held, furthermore, that not only were basalts and similar rocks of sedimentary origin, but that the crystalline schists, gneisses, etcetera, had originated in like manner, and adduced as further proof of this fact the fact that bodies of crystalline marble were in places found inclosed in these schists, which showed that the inclosing rocks had never been subjected to heat, since, had this been the case, the carbonic dioxide would have been expelled from the marble and quicklime only would have remained.

Hutton, on the other hand, following the teaching of the Plutonists, held that the crystalline schists and other crystalline rocks had solidified from a molten condition, and that the magmas from which they had developed would, if cooled very slowly, yield distinctly crystalline, or even coarsely crystalline, rocks, and that even "stones[2] of the calcareous genus

[2] Playfair's Illustrations of the Huttonian Theory, vol. 1, p. 45. Edinburgh, 1822.

have been reduced by heat into a state of fluidity; thus the saline or finer kinds of marble that have a structure highly crystallized must have been softened to a degree little short of fusion before this crystallization could take place," and that he believed it to be possible that "calcareous earth under great compression may have its fixed air retained in it, notwithstanding the action of intense heat, and may by that means be reduced into fusion or into a state approaching it."

Here was a well defined issue between the two great camps into which the geological world was then divided. On its outcome depended the explanation of the nature and origin of the rocks constituting a large portion of the earth's crust. They could not settle the dispute by observation in the field, but it was triumphantly decided by recourse to experiment. To Sir James Hall,[3] of Edinburgh [1761-1832], who was an intimate friend of Hutton, is due the credit of having carried out this epoch-making experimental demonstration.

Taking first the "whinstone," or intrusive olivine basalt of the district about Edinburgh, and later the lavas from Vesuvius and Etna, he fused them in a reverberating furnace and obtained from the fused material by rapid cooling a perfect glass. When, however, the rock was fused and cooled more slowly, he obtained a product which, while not like whinstone, was of an intermediate character, like the "liver of an animal," to use his own quaint expression, and often containing "a multitude of little spheres having a dull or earthy fracture." This we now know to be a glass filled with devitrification products, and he makes some interesting observations with reference to the sudden hardening of the glass, even if the temperature remains constant, as it passes into this devitrified condition.

Finally he found that if the fused mass was cooled very slowly, during a period of several hours, he obtained "a substance differing in all respects from glass and in texture completely resembling whinstone."

He thus demonstrated experimentally that, contrary to the opinion of the Neptunists, a crystalline rock might be produced by the cooling of a fused magma and thus be of igneous origin.

Hall[4] then carried on a long series of most brilliant, interesting, and ingenious experiments, in which he submitted powdered chalk to a red or white heat in closed gun-barrels or porcelain tubes. A portion of the chalk was thus disassociated, while the remainder was submitted to a high pressure by the carbonic acid gas thus produced. The manner in

[3] Experiments on whinstone and lava. Trans. Roy. Soc. of Edinburgh, vol. v, 1805.

[4] Sir James Hall: Account of a series of experiments showing the effect of compression in modifying the action of heat. Trans. Roy. Soc. of Edinburgh, vol. vi, 1812.

which the many unforeseen difficulties, which always present themselves in such an investigation, were surmounted and the infinite patience with which the investigation was followed out mark Hall as an investigator of high rank. He carried out some 500 experiments, and a whole battery of gun-barrels burst in the course of the investigation; but he succeeded eventually in converting the powdered chalk by heat and pressure into a material which was to all intents and purposes a fine-grained marble, thus proving that the presence of this rock in a complex of crystalline schists could not be taken as evidence that these rocks were aqueous precipitates, but that, on the contrary, it conveyed the suggestion that they had during their formation been submitted to conditions of great heat and pressure.

The arguments of the Neptunists were thus finally overthrown by Hall's investigations, and he well merits the honor which is bestowed on him when he is called "the Father of Experimental Geology."

The recognition of the fact that much valuable information, contributing in no small measure to the understanding of many recondite processes which are at work in nature, might be obtained through experiments, where the conditions which obtain in the earth's crust are reproduced as closely as possible in the laboratory, now commenced to draw the attention of an ever increasing number of geologists to the importance of experimental work. Among these may be mentioned Sorby, Pfaff, Kick, Michel Lévy, Fouqué, Cadell, Doelter, Spring, Meunier, Bailey Willis, and especially Daubrée, who for over forty years devoted himself untiringly to the pursuit of experimental geology and whose great work, entitled "Études synthétiques de Géologie Expérimentale," published in 1879, will ever remain one of the classics in this subject.

One of the lines along which such experimental study has yielded important results to geological science may be referred to briefly, namely, the experimental study of the development of mountain ranges.

The Alps, situated as they are in the very heart of Europe, have been subjected to more continuous and intensive study than any other mountain range in the world. The serious attempts to unravel their structure may be said to have extended over the lifetime of three successive Swiss geologists—De Saussure, Arnold Escher von der Linth, and his pupil, Albert Heim, representing the period from 1740 to the present time.

In the earlier part of this period the mountain range was considered to be a jumbled assemblage of rock-masses without definite or recognizable structure of any kind—a mere chaos of broken pieces of the earth's crust. Gradually it came to be seen that in addition to more or less massive rocks of obscure origin there were stratified elements in the vari-

ous massifs. These beds, however, were highly inclined. "We are still ignorant," writes De Saussure, "by what cause these rocks have been tilted. But it is already an important step among the prodigious quantity of vertical strata in the Alps to have found certain examples which we can be perfectly certain were formed in a horizontal position." Then it came to be recognized that these inclined strata were portions of great folds, and later that the mountain system as a whole had originated through the complicated folding of a belt of country.

It was Sir James Hall who, in 1812, a few years after De Saussure's death, insisted that the cause of this folding was to be found in great tangential pressure in the earth's crust, developing horizontal thrusts of immense magnitude. In order to demonstrate that such forces could produce the results observed, he constructed a machine in which a series of layers of cloth of different sorts, alternating with stuffs of other kinds, were submitted to great lateral pressure while under a heavy vertical load. Thin layers of clay were in a later series of experiments substituted for the cloth. By these experiments Hall was able to show that folding of the type seen in mountain chains could be developed by such lateral thrusts, and that in his particular experiments the convolutions of the Silurian strata of the Berwickshire coast were reproduced in a striking manner.

He was followed after a long interval by Cadell, who, in 1888, carried out a series of experiments in which alternating layers of sands of different colors, clay, and plaster of Paris, resting on a bed of plastic wax, were deformed in a similar manner, with a view more particularly to ascertaining under what conditions of pressure overthrusts such as those which were being discovered in the highlands of Scotland would be developed.[5]

Among some of the important results which he obtained were the facts that overthrusts did not necessarily originate in the disruption of overturned folds, but were often produced directly by horizontal thrusts, and that a deep lying overthrust might pass upward into an anticlinal fold and thus never come to be visible as an overthrust at the surface.

Daubrée,[6] Pfaff,[7] Meunier,[8] Schardt,[9] Reyer,[10] and others carried out

[5] Experimental researches in mountain-building. Trans. Roy. Soc. of Edinburgh, vol. xxxv, 1888, p. 337.

[6] Loc. cit.

[7] Der Mechanismus der Gebirgsbildung. Heidelberg, 1880.

[8] La Géologie Expérimentale. Paris, 1899.

[9] Études Geol. sur le Pays-d'Enhaut Vaudois—3′ partie, A. Mechanism des Dislocations. Bull. de la Soc. Vaudoise des Sciences naturelles, 1884.

[10] Geologische und Geographische Experimente. Leipzig, 1892-1894.
Ursachen der Deformationen und Gebirgsbildung. Leipzig, 1892.

experimental work on the same lines, directed to the solution of special phases of the complex problems presented by the intricate structure of folded mountains.

Mellard Reid,[11] on the other hand, investigated the action of heat, in the development through expansion and flow, in sheets of lead and other metals, of structures analogous to those displayed in many mountain ranges.

These led up to the more extended and important investigations carried out by Bailey Willis.[12]

In these investigations, employing a machine of the same general type as that used by the earlier experimenters and layers of wax of different degrees of plasticity, moving by tangential thrust and under a vertical load produced by a heavy layers of shot, which consequently adjusted itself to the varying form and inclination of the folding surface, Bailey Willis studied the deportment under different conditions of load of a series of thin beds, a succession of thick beds, and of a sequence of thick and thin beds. He ascertained the very important rôle played by stronger layers in transmitting thrust for long distances and developing competent arches, and also the marked manner in which the whole character of the folding was influenced by initial dips in a stratified series.

This study served to throw very important light on the mechanism of the development of the type of folding displayed by the Appalachian Mountains.

A further advance was made in this line of experimental work by Paulcke[13] in 1912. The aim which Paulcke set before him was to reproduce in his experiments the types of structure displayed by certain specified mountain ranges, and having learned how to reproduce each type at will, to analyze the precise causes which determine the development of one or other type of structure, as the case may be. He selected for study three types of mountain structure, namely, those of:

1. The Jura.
2. The western Swiss Alps.
3. The eastern Lepontine Alps.

Employing an apparatus similar in a general way to that used by Bailey Willis, he succeeded eventually in being able to reproduce at will any one of these structures, and ascertained from his experimental work that the development of the differences which characterize these several

[11] The Evolution of Earth Structure. Longmans, Green & Co., London, New York, and Bombay, 1903.

[12] The mechanics of the Appalachian structure. U. S. Geol. Survey, 13th Ann. Report. Washington, 1893.

[13] Das Experiment in der Geologie. Karlsruhe, 1912.

types of structure is determined, in the first place, by the petrographical character of the sediments within the complex—that is, their relative hardness—and their position in relation to one another. In the second place, by the character of the basement on which the sedimentary strata lie, and,thirdly, by the amount of vertical loading to which they are subjected during the action of the tangential thrust.

Paulcke's work thus in certain directions develops the principles discovered by Bailey Willis and represents the last of a series of experimental studies which have thrown much light on the mechanism of mountain-making.

But while much light was being thrown on the mechanics of mountain-building by the experimental method, another and extremely obscure, but highly interesting, group of phenomena was attracting attention, namely, the movements and changes which take place within the substance of the rocks themselves when subjected to these enormous forces by which they are folded into mountain chains. The results of these forces are seen in their most striking forms in those rocks which have been buried in the deeper parts of the earth's crust, where these forces act most intensely. The phenomena are those of schistosity or foliation, rock-flow, and the accompanying aspects of metamorphism.

The schistose, foliated, or gneissic structure displayed by these rocks was formerly regarded as an imperfect or partially obliterated bedding. Fox,[14] however, in 1837, claimed to have determined experimentally that a current of electricity passed through damp clay would render the mass schistose, and on the basis of this observation for a time many of the leading geologists looked to electric charges passing through the earth's crust as a probable cause of the development of schistosity. Sorby,[15] however, on the ground of a microscopic study of these schistose rocks, pointed out that movements under pressure determined the development of this peculiar structure and showed experimentally by submitting a stiff mass of micaceous iron ore and clay to heavy pressure that in such a mixture movements under pressure would produce a distinct foliation.

A number of other investigators followed up this line of experimental work, among whom may be mentioned Tyndall, Daubrée, and Tresca, and showed that under such movements in plastic masses any scaly mineral present will become orientated in the direction of the movement, giving rise to a schistose structure in the mass. Tyndall[16] even showed that in

[14] Mem. Royal Cornwall Polytechnic Soc., 1837.

[15] Edinburgh New Phil. Jour., vol. lv, 1853, p. 437, and London, Edinburgh, and Dublin Phil. Mag., vols. xi and xii, 1856.

[16] Comparative view of cleavage of crystals and slate rocks. Royal Institution of Great Britain, June 5, 1856.

a mass of pure wax differential pressure will develop a well defined schistose structure through the flattening in one plane of the minute globules of which that material is composed. But the question as to whether pressure alone could bring about such movements in the solid rocks of the earth's crust remained unanswered.

David Forbes,[17] as early as 1855, carried out a series of experiments in which slabs of rock were embedded in the floor of a blast furnace, and from these concluded that not only pressure but also heat, which effected a partial recrystallization of the constituents of the rock, was needed to produce foliation.

A school of later observers, again, have held that the foliation of the crystalline schists is a phenomenon due to a process of solution and redeposition of the constituent minerals of the rock under conditions of pressure in the presence of moisture.

While, therefore, all observers agree that pressure is an agent in the production of schistosity or foliation, the relative part played in this process by pressure, heat, and solution has remained a matter of individual opinion.

When mapping the very extended area of Precambrian rocks embraced by the Haliburton and Bancroft region of the Laurentian peneplain in southeastern Ontario, this ancient question as to the part played by these three factors respectively in the development of the foliated or gneissic structure, which is seen almost everywhere in more or less pronounced development over these thousands of square miles of glaciated exposures, continually presented itself.

It was impossible to solve the question by the closest and most attentive observation in the field or by the most careful petrographic study of thin-sections of the rocks themselves. It seemed, however, that some light might be thrown on the problem by the aid of further experiment, for in experimentation it might be possible to separate the three factors of pressure, heat, and solution and investigate the action of each separately.

It was evident from the field study that the limestones of this ancient complex were the most plastic element in the series and yielded most readily to the forces which had produced movement with its concomitant development of schistosity. It appeared, therefore, that this rock would lend itself most readily to trial by experiment.

Pressure alone was first employed. And in order to reproduce the conditions of pressure found in the earth's crust, a differential pressure—

[17] On the causes producing foliation in rocks. Quart. Jour. Geol. Soc., 1855, p. 184.

that is to say, a pressure from all sides, but much greater in one direction than in the others—was required. This condition was secured by inclosing very accurately turned and polished cylinders of Carrara marble in heavy tubes of nickel steel of peculiar form and fitted with pistons of chromium tungsten steel.

It was found that by the application of differential pressure alone a perfect deformation of the marble was obtained—the rock flowed as a column of soft metal might. If the movement was allowed to go forward very slowly, the rock was deformed without loss of strength.

The action of pressure combined with heat was then examined, and it was found that when the rock was heated to 300° C. or 400° C.—a heat which is too low to disassociate the molecule—the movement takes place more readily, and may therefore be carried out more quickly without impairing the original strength of the rock.

The third factor, that of moisture, was then introduced and the rock was slowly deformed through a period of two months, while maintained at a temperature of 300° C. and with steam being forced through it while the deformation was going forward. The presence of moisture in this experiment was found to produce no noticeable effect; the character of the deformation was identical with that where pressure and heat alone were employed.

A study of thin-sections of the deformed limestone, moreover, showed quite clearly the nature of the movement which had taken place. It was a movement on the gliding planes of the individual calcite crystals composing the rock, accompanied by a fine polysynthetic twinning, each of the original grains becoming in this way elongated, so that a schistose structure was developed in the rock.

This structure, furthermore, is exactly that which is displayed by certain of the limestones of highly contorted regions, so that we have experimental demonstration that in these cases pressure alone would have been quite adequate to produce the phenomena observed.

Leaving this question of the deformation of marble, we may turn to other rocks.

When various impure limestones, such as those which are commonly found in the Paleozoic and Mesozoic succession, were examined, it was found experimentally that they could also be deformed by simple pressure, with a development of the same schistose structure. This is also true of alabaster, steatite, serpentine, and other of the softer rocks.

With the harder rocks, such as granite, diabase, and essexite, it was again found that pressure would produce a deformation of the rock with the development of a schistose or foliated structure. In these cases, also,

the deformation was distinctly facilitated by heat (350° C. to 450° C.). The structure, however, was no longer developed by a movement on the gliding planes of the constituent minerals, but was produced chiefly by a granulation of the minerals and the alignment of the granules in the plane of the schistosity thus developed. The structure is identical with that seen in mylonite and many augen gneisses, so that experimental proof is afforded that such rocks may be produced in nature by the action of pressure alone, but that the development of the structure is more readily effected if the rocks are hot.

So far as these types of rock are concerned, then, schistosity or foliation may be produced by pressure alone, without heat and in the absence of moisture.

To recur for a moment to the deformation of marble.

It will be found that when most of the foliated or schistose limestones which occur in nature are examined under the microscope, they show little or no evidence of pressure phenomena, such as those above described. The rock frequently presents the appearance of a mosaic of equidimensional grains, such as might be expected to have been developed by an original crystallization of the material. The schistosity in these cases is produced by an alternation of thin laminæ of larger and smaller individuals of calcite or by the parallel arrangement of other minerals existing as impurities in the rock.

A schistosity of this character, which is to be observed not only in limestones, but in very many other crystalline schists, has by most authors been regarded as susceptible of explanation only as being due to recrystallization of the rock, through the agency of moisture present in the rock as the deformation was going forward. Some very interesting experimental work which has been carried out in recent years in the Geophysical Laboratory in Washington has, however, a very important bearing on this question.

Reference has already been made to the experiments of Sir James Hall, in which he obtained a white crystalline marble by heating chalk under high pressure, experiments which were repeated later by Gustave Rose and the results confirmed. Hall believed that this change was due to a partial or complete fusion of the marble with subsequent crystallization on cooling.

It has recently been found, however, that if finely powdered or loose, finely crystalline aggregates of a mineral which is not destroyed by heat are submitted for a considerable time to a temperature which, while high, is still considerably below the fusion point of the mineral, the powder will become progressively coarser in grain. The mineral slowly volatil-

izes and the loss from the various grains is, of course, proportionate to their surface area; the smaller grains, having a surface area relatively great as compared with their mass, have a tendency to decrease in size and disappear, while the larger grains, owing to their greater mass, condense this vapor on their surface and thus increase in size under the operation law of surface tension.[18]

The process is essentially the same as that which takes place when a very fine-grained precipitate of, for instance, barium sulphate is kept warm for some time before filtering, the grain of the precipitate thus coarsening by a process of solution and deposition. This coarsening of finely divided silicates by submitting them to a high temperature when in a state of very fine powder is now, I am informed by Dr. F. E. Wright, regularly employed at the Geophysical Laboratory in Washington for the purpose of obtaining from such fine-grained aggregates crystals sufficiently large for purposes of crystallographic measurement or for the determination of their optical properties. The process in the case of many minerals goes forward quite rapidly.

Now this fact, experimentally determined, has probably a very important bearing on the question of the origin of the metamorphic rocks in general, and especially of those crystalline schists which present the mosaic structure to which reference has been made above; for the materials out of which they have been developed were fine in grain and crystallized not only under great pressure, but when deeply buried and therefore at a high temperature. In many cases they may have been subjected to long-continued heat after the parallelism of constituents had been developed in them by movements under pressure, in which case this coarsening of grain with the final development of a mosaic structure, amounting practically to a recrystallization of the mass, would result.

This is a new principle in metamorphism, but one which is probably of wide-reaching significance.

It may be noted in this connection that any malleable metal, when made to flow by rolling or hammering, is deformed by the elongation of its constituent grains through movements on their gliding planes, the hammered or rolled metal thus taking on a structure identical with that in the marble deformed by pressure in the experiments mentioned above. If the metal is then heated and allowed to cool slowly, this fibrous structure completely disappears and is replaced by a typical mosaic structure identical with that ordinarily seen in natural marbles. Under this treatment a complete recrystallization of the metal takes place in the space of a few minutes and without the point of fusion being even approached.

[18] See also Justus Roth: Allgemeine Geologie, Bd. iii, 1, p. 154.

In this connection the experimental work carried out by Spring[19] should be mentioned. Although certain of Spring's results have been called in question by Friedel[20] and Jannettaz,[21] the whole field has been reviewed by Johnston and Adams,[22] of the Geophysical Laboratory at Washington, and the bearing of Spring's work clearly set forth. Spring has demonstrated that under high pressure certain substances unite chemically with the production of new compounds. Thus copper and sulphur when compressed to 5,000 atmospheres unite to form a black crystalline cupreous sulphide, while barium carbonate and sodium sulphate yield under a pressure of 6,000 atmospheres barium sulphate and sodium carbonate. Johnston and Adams, however, have pointed out that a careful distinction must be made between simple cubic or hydrostatic compression and differential pressure which gives rise to a shearing movement or flow within the mass. The former produces but little effect in developing chemical change; the latter, however, does in many cases produce important alterations in chemical composition and is in a way analogous to a long-continued grinding together of the reacting substances in a mortar. In some cases the apparent interchange may be due to a process of diffusion occurring between the particles of the two substances brought into intimate contact by the pressure to which they are submitted. We have, by submitting a mixture of certain salts to such differential pressure, giving rise to flow, obtained foliated structures with a development of new compounds, which reproduce in a striking manner certain structures seen in the crystalline schists of highly contorted portions of the earth's crust.

Another very important fact is that when minerals of an acicular habit are developed in a rock which is undergoing deformation by differential pressure these new minerals grow in the mass with their longer axes orientated at right angles to the direction in which the pressure is being exerted, as shown by the experiments of F. E. Wright[23] on certain glasses which were allowed to crystallize when flowing under differential pressure, as well as by a series of experiments by the writer, the results of which have not as yet appeared, in which gypsum is converted into a lower hydrate while submitted to heavy differential pressure. In these cases crystalline rocks result, showing distinct foliation, the plane of this

[19] Recherches sur la Propriété que possèdent les corps de se souder sous l'action de la Pression. Revue Universelle des Mines (and many other papers).

[20] Bull. Soc. Chem. (2), vol. xxxix, 1883, p. 626.

[21] Ibid. (2), vol. xl, 1883, p. 51.

[22] On the effect of high pressures on the physical and chemical behavior of solids. Am. Jour. Sci., March, 1913.

[23] Schistosity by crystallization—a qualitative proof. Am. Jour. Sci., Sept., 1906.

foliation being at right angles to the direction of the force producing the movement.

In all these cases, therefore, schistosity is produced by pressure or by pressure combined with heat, but in the absence of moisture.

The question of the part played by solution under pressure in the development of the crystalline schists is one of great importance. Speaking generally, when a crystal is strained its solubility on the strained face is increased. Consequently a strained crystal in contact with a saturated solution of any solvent dissolves on the strained faces and is redeposited where there is no strain. It would thus seem that in the presence of moisture great differential pressure, even at low temperatures, might if long continued effect a gradual recrystallization of a massive rock with the development of a foliated or schistose structure in a direction at right angles to the direction of maximum pressure. Becke, Grubenmann, and others have seen in this conjectural process the chief factor in the development of great series of crystalline schists which are met with in the Alps and elsewhere and whose structure they designate as "Krystallizationsschieferung."

This process of solution which seems to have taken place, in some cases at least, and to have resulted in the development of a schistose structure in the rock, has not as yet been submitted to investigation by experiment. The phenomenon attributed to it may have been produced by recrystallization induced by pressure and heat.

Enough has been said to show that it is impossible in the present state of our knowledge to determine in every instance the relative importance of the rôle played by pressure, heat, and solution in the development of a body of crystalline schists. Some progress has been made in this direction, but there is still a very wide and fruitful field open for experimental work. It would be a much appreciated boon if by such investigation it were possible to rescue our successors from that state of despair described by Sharpe "as the first impression of an observer entering a district of gneiss or schists in search of order in their arrangement."

I have dwelt at some length on what is really a single great field of experimental effort—that, namely, which has as its goal a correct understanding of the manifold phases of the action of pressure, heat, and solution as displayed in the mechanism of mountain-making and in the development of the crystalline schists, which is another and accompanying manifestation of the same agencies.

There are, however, many other lines along which experiment in geology has made notable conquests and in which brilliant results have been achieved.

Time does not permit me to do more than merely enumerate a few of these.

Among the best known of these is the work of Fouqué and Lévy,[24] Morozewicz,[25] and others on the synthesis of igneous rocks and the elucidation of the processes and conditions under which the crystallization of these rocks go forward.

The studies of the melting points of the rock-forming minerals, their solubilities in silicate magmas, of eutectic mixtures, and magmatic differentiation, carried on by the staff of the Geophysical Laboratory in Washington, by Doelter[26] and his pupils, by Vogt[27] and others.

The investigations which have been made in recent years into the true nature, mineralogical composition, and chemical relations of that great series of artificial rocks which are daily coming to be of greater importance in the arts of peace and war—the cements.

The extended investigations which are now being carried on in the Geophysical Laboratory, in elucidation of the field studies of Graton, into the composition of copper ores and the problems of secondary enrichment—investigations which are not only of great significance from the standpoint of pure science, but which promise to have a far-reaching economic value.

As examples of experimentation in very different fields, the work by Gilbert[28] and Murphy on the transportation of debris by running water, that of Andrée,[29] Lang and Peterson[30] on the laws of geyser action, and that by Daubrée[31] on the development of joints and fractures by torsion may be instanced.

The Future of experimental Geology

Looking into the future, it is clear that the great conquests which await experimental geology are to be won through the application of accurate measurement to all experimental work. We are passing from the qualitative to the quantitative in experimental geology. To carry out such exact investigations in the regions of high temperature and great pressure, by which alone we can hope to unlock the secrets of the earth's crust, will require not only able workers—men of skill, resource, and imagina-

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24 Synthese des Minéraux et des Roches. Paris, 1882.
25 Tscher. Mitt., 19, 1, 1899.
26 Handbuch der Mineralchemie. Dresden, 1912.
27 Die Silikatschmelzlösungen. Christiania, 1903.
28 U. S. Geol. Survey, Professional Paper No. 86, 1914.
29 Neues Jahrb. für Min., Bd. 2, 1893.
30 Neues Jahrb. für Min., Bd. 2, 1889.
31 Études Synthétiques de Géologie Expérimentale.

tion—but very elaborate equipment and large endowments. The chief advances, therefore, are to be expected from great laboratories equipped for this special work, such as the Geophysical Laboratory of the Carnegie Institution at Washington, to which frequent reference has been made above, and from which, under the direction of Doctor Day, and with investigators of such distinction as F. E. Wright, Washington, Sosman, Johnson, Bowen, and others who have been and still are connected with its staff, a continuous series of publications of the highest value has issued, which, being based on the results of accurate observation and exact measurement, will remain permanent contributions to geological knowledge.

By such investigations petrology will be made an exact science, and it is difficult to overestimate the advances which may be thus made in many other branches of geology in that new era to which Daubrée[32] refers in the closing sentence of his great work on metamorphism, when he says:

> "Géologie a enfin abordé une nouvelle période où elle s'éclairera dans ses phénomènes de tout ordre, chimiques, physiques et mécaniques, par l'expérimentation synthétique, subissant ainsi des phases analogues à celles que la physique a traversées pour arriver, de l'état où la prit Galilée, au point où nous la voyons aujourd'hui."

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[32] Études et Expériences synthétiques sur le Metamorphism. Paris, 1860.

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CONTENTS

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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POST-GLACIAL UPLIFT OF NORTHEASTERN AMERICA[1]

BY HERMAN L. FAIRCHILD

(Read in abstract before the Society December 27, 1917)

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INTRODUCTION

For over half a century the certainty of some post-Glacial submergence of northeastern America has been recognized, yet the maximum submer-

[1] Manuscript received by the Secretary of the Society January 14, 1918.

gence or, conversely, the height of the subsequent uplift and the limits of the affected area have not been determined. In recent years there has been a tendency to minimize the diastrophic movement and even to deny its occurrence along the south border of the glaciated territory; but Professor Shaler believed that Marthas Vineyard had been submerged 300 feet and Mount Desert 1,300 feet, and several eminent geologists have found abundant and positive proof of Pleistocene submergence of the lower Hudson Valley and New Jersey (see number 84 of the bibliographic list, page 288). The radical difference of opinion on a subject open to direct observation is a problem in psychology.

Canadian geologists have recorded many localities of marine fossils at high altitudes in the Saint Lawrence and Ottawa valleys and eastward, with the other attendant evidences of standing water. Similar evidence is abundant in New England, but at less altitude. This proof of deep submergence while the Labradorian ice-sheet was passing off led the earlier geologists to overemphasize the work of floating ice and icebergs in the explanation of glacial phenomena. The later recognition that most glacial features are the effects of land ice has resulted in the comparative neglect, especially by geologists of the United States, of the fact of deep marine submergence. With emphasis on direct glaciation, we have neglected the observations of the "diluvialists" and "icebergists" and have minimized the effects of oceanic waters. However, it must be admitted that in the deep marine waters of the valleys of Canada and New England the students of half a century ago had good basis for the theory of iceberg agency.

In the recent examination of eastern Canada and New England[2] the study has been systematically extended from an area in which the post-Glacial uplift had been well determined. The Hudson, Champlain, Saint Lawrence, and Connecticut valleys hold a clear record of the earliest and deepest sealevel waters and afford a long base-line for the extension of the isobases. In the Hudson-Champlain depression is inscribed a record of Pleistocene history for all the time during which the waning Labradorian glacier lay on any part of the United States. On this meridian the tilted uplift has been determined as over 800 feet on the north boundary of Vermont. The results of previous study are on record in papers numbers 81 to 85 (see bibliography), but the detailed description of the critical features in New York is awaiting publication by the New York State Museum.

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[2] The writer makes grateful acknowledgment of financial aid from the research fund of the American Association for the Advancement of Science.

METHODS OF STUDY

The failure to determine the facts relating to Pleistocene submergence and to reach agreement in opinion must be due either to inherent difficulty of the study, or to defect in methods of study, or to lack of clear, unbiased vision. Probably all of these factors contribute, but especially the second. A discussion of study methods is in order.

(1) Successful attack of the submergence (uplift) problem requires correlation of data over the entire glaciated area, but the studies have usually been local and detached.

(2) Equality of uplift over considerable area has too often been assumed; but this is impossible, except perhaps in the central area of the upraised dome.

(3) Systematic exploration must postulate an irregular doming uplift, with the horizontal lines of equal uplift (isobases) curving about the convexity and with declining gradients in radial directions. The gradients on the radii must diminish to zero both at the margin and near the center of the domed area.

(4) The critical element everywhere is the maximum uplift in each location, the determination of the initial or summit shoreline. This is the difficult and elusive element, and most recorded elevations give only the conspicuous, inferior phenomena.

(5) For any district a working theory is needed of the approximate direction and spacing of the isobases or, in other words, the direction and gradient of the steepest slope. Then the location of two positive stations on the summit level affords a reference or base for further search, and with accumulation of data the search becomes proportionately easier.

For success in determining at least approximately the total uplift over a large area the writer has relied chiefly on criteria not generally recognized. Instead of depending on bars, cliffs, and features of wave work, which are excellent when found, but which are capricious, commonly wanting, and rarely produced as initial or summit inscriptions, he has depended primarily on stream deltas. These are almost unfailing and are positive indications, even if not very precise, of the initial water plane. In a new or unknown district the primary determination of the approximate level is made on larger streams, *preferably in south-leading valleys,* and the more precise determination of the summit water level is made by examination of the smaller deltas of lateral streams and the shore features in the vicinity. As the railroads, with their elevations giving datum for altitudes, nearly always follow river valleys, it has been feasible to traverse rapidly a large territory with positive results. A proof of the sound-

ness of the method and the truth of the results is the fact that in many cases predictions of the location of deltas and of the height of the summit plane have been closely verified.

In his discriminating and admirable work on the surficial geology of Maine, Mr. George H. Stone recognized the utility of deltas in determination of water planes (68). He writes, page 483, as follows:

". . . If we should find a great change in the coarseness of the sediments taking place within narrow vertical limits, proving considerable slowing of the waters at that point, and especially if this were observed in several valleys at the same relative position to the lines of highest elevation, as determined by observation of the coast beaches, we should have probable proof that the streams of the land poured into the sea at those points. Thus far I have not been able to apply the method satisfactorily, in part owing to the rarity of known elevations in these valleys. Where the streams were large compared to the breadth of the valleys it is doubtful if this method can be applied with certainty. The broader and shorter valleys off the lines of the glacial rivers are the most promising cases for the application of the method."

The discrimination and caution observed in the use of deltas for finding water planes will be described in the next chapter.

Criteria for Determination of Water Levels

CLASSIFICATION AND DISCUSSION OF THE CRITERIA

A brief discussion of shore features and the character of the primitive or summit marine plane and the criteria employed in their study will clarify this subject.

In the order of importance or usefulness the classes of features which may be used for the location of static water levels are listed as follows:

1. Stream deltas.
2. Bars; wave-built embankments.
3. Wave-erosion lines; cliff and terrace; boulder fields.
4. Drift-denuded surfaces; bare-rock areas.
5. Wave-smoothed stretches; leveled kames and sand-plains.
6. Valley plains.
7. Marine fossils.

The second class—bars of cobble, gravel, or sand—is the least common in occurrence, but is ranked high because of the unequivocal, positive character and reliability for even the less experienced student. However, by themselves bars are no conclusive proof of initial or summit level, even if they lie against slopes which offer no evidence of higher stand of waters. Such negative evidence is unreliable. It is a mistake to rely

wholly or even mainly on features of wave construction or wave erosion—classes 2 and 3. At the initial or summit level of the sealevel waters with the short life of the latter, these are the rarest of features, but when found are, of course, conclusive proof of standing water. The same is true of number 7; but it must be understood that marine fossils never mark the initial water level and are usually far below, 100 or 200 feet.

For close determination of the standing water surface, heavy deltas, those of vigorous and well loaded streams, are not so precise criteria as bars and cliffs. But their practically unfailing occurrence at the highest or initial water level makes them more useful over large areas, and for long distances in comparison of far-separated valleys they are sufficiently accurate.

Because of their more common occurrence, the classes 3 to 6 are more useful, taken together, than class 2 for the geologist with experience in shoreline study; but they are less definite and often equivocal, and experience and skill are required for confident use. They may vary in character with the lithology, the nature of the drift, and the topography of a district. When well determined they have value at least as showing minimum uplift, which is all that classes 2 and 7 give. The best use of these features is for confirmation of the shoreline over intervalley areas or between more definite features.

SUMMIT DELTAS

By far the most useful class of shore features in locating summit water levels is stream deltas, the deposits built at the debouchure of streams in static waters. They are practically certain of production at the initial level of the receiving water body, are scarcely ever wholly destroyed, and are quite unmistakable. Any possible conditions that might inhibit construction of deltas in the far-inland valleys must be exceedingly rare.

In the large sense this class of deposits might include the broad valley plains of river detritus built in lowering waters in the downstream sections of an uplifted main valley. But the term as here used is meant to cover only the more or less localized bodies of coarse detritus which have an evident genetic relation to the work of some living or extinct stream, without distinction of shape, size, or composition. It is a matter of origin by interaction of flowing and static water. Perhaps an addition to our terminology is desirable.

The mistake has been made of regarding broad sand or silt plains as marking the highest or summit level of the standing waters. Except as lateral floodplains, such fine detritus is not dropped near the water surface. The broad, smooth plains are nearly always of inferior level. In

wide valleys where waves were competent to distribute detritus, or in constricted valleys where the volume of the river was sufficient to produce some current in the estuary, the plains could not form at the water surface. The phenomena of the initial or summit level may be miles away, far inland, and much higher in altitude.

When extensive delta sand-plains are used as criteria for summit levels they must be judged by the local or neighboring conditions and no special rule or quantitative expression can be given. Many factors are involved: the volume and velocity of the contributing stream; the volume and character of the detrital load, and the capacity of the water body, with the topography of the under-water slope.

The small deltas built by little streams, even wet-weather runs, in quiet or shut-in waters are much better indexes of the precise level of the standing water than the heavy deltas of large streams or the broad plains in the open valleys. Of course, these small deltas require sheltered locations, where waves and shore currents are incompetent to remove the delta stuff. The tiny benches, perhaps only rods or yards in area, on the border of small ravines or gullies give the true summit level of secluded waters; and even on the walls of exposed valleys the small-stream deltas may be the best criteria of the primitive water surface. Such small features have commonly been ignored, because they were small and inconspicuous, detached, usually inland, and not evidently related to the obtrusive features of the great valleys.

The deltas of the higher levels in the lateral or inland valleys have been attributed to glacial waters, local ice-border lakes, or pondings due to ice-lobes, and consequently have been slighted. The fact that under certain conditions glacial lakes faced the receding ice-margin certainly requires that caution be used in the study of the water levels, especially in north-sloping valleys. In this study the main reliance is placed on streams with southward flow, or having such direction and relation to the large topography as to avoid blockade by any lobation of the ice-front.

Deltas and channels of glacial drainage are most positive records of the initial water level. The ice-border streams were ephemeral and they dropped their detritus in the waters that laved the ice-margin, which were then at maximum altitude relative to the land. Sand-plains which can be correlated with extinct glacial streams that debouched in marine estuaries must give the primitive water level. In the Hudson and Champlain valleys the glacial stream channels and deltas have afforded excellent, precise data.

Discriminative Criteria

GLACIAL WATERS

The study and explanation of puzzling or equivocal features, like high-level sand-plains, appears to have been evaded by referring them to the limbo "glacial." The term is overworked. It is unscientific to attribute such plains and unexpected shore features to glacial waters without proof, and it is unfair when other explanation has been given. It seems necessary to discuss the criteria for discrimination of the glacial plains.

In valleys declining northward, or in any direction toward the waning ice-sheet, ice-impounded or glacial waters were certainly held. This may also be true of some valleys with only a part of their course so oriented as to permit temporary blockade. The Androscoggin Valley is a possible example. In all such valleys high-level deltas and shore features are regarded with suspicion and are not used as evidence of sealevel waters, at least not without careful discrimination. Many such examples of ice-damned valleys are found on the north-facing slopes of the basins of the Great Lakes and on the south wall of the Saint Lawrence Valley in New York, Vermont, and Quebec. Many of the glacial lakes in New York have been the subject of published papers.

Glacial lakes were practically impossible in the great south-leading valleys like the Hudson and Connecticut, the reasons being given in a former paper (84, pages 291-292). The same is true of all valleys which were normal to the glacier front and opened freely seaward, like those of Maine and New Brunswick.

The glacial waters, which were temporarily held in embayments of the walls of large valleys, like the Hudson, Penobscot, or Saint John, did not commonly produce any important features or any difficult of diagnosis. Deltas and short features in the lateral valleys are the only ones of doubtful origin, and of these some discussion is desirable.

The damming of waters, with efficient length of life in the tributaries of the south-leading trunk valleys, required decided lobation of the ice-margin, probably to an amount not common, and something more than a low tongue of the thin edge of the ice-front. But such pondings in the lateral valleys did sometimes occur. High-level phenomena above the well-determined marine level are so explained.

To have a long life and steady level, so as to produce good shore features, glacial lakes, like any other class of lakes, required fixed outlets. That means outlet over land, and such outlet should be located, if a long-lived, constant-level glacial lake is postulated under doubtful conditions. Most glacial waters had their outflow along the margin of the

ice-lobe, as ice-border drainage, and such dams were weak and shifting. In consequence of this fact most glacial waters were ephemeral in life, inconstant in level, and sudden or spasmodic in extinction. The last condition is especially important. Glacial sand-plains rarely exhibit any regular succession of terraces, because of the sudden or irregular down-draining of the waters. By contrast, the ocean-level waters of the estuaries and their branches fell away (relative to the land) by steady, slow decline, and the sand-plains built in these waters commonly present a series of terraces, even down to the present stream floodplains.

Sand-plains built in glacial waters may reveal some evidence of the presence of the ice-margin; shown by ice-contacts, or by kettles, or by included till masses, and less clearly by irregular deposition and poorly assorted materials. Some deltas deposited in sealevel waters might have been built near or even against the ice-front and might contain unassorted materials. Any deposits made by glacial drainage, directly from the ice-front or along the ice-border, are not likely to have good delta form or relationship to land drainage, but may be good index of the summit sealevel.

The most important distinction between glacial sand-plains and estuary plains is the fact that the former, in independent, separated basins would have no genetic correspondence in altitude. A series of detached lakes, with accidental correspondence of height over a long distance, is very improbable. But, on the other hand, the plains built in the estuaries have close accordance in altitude over hundreds of miles along an uplifted and tilted water plane. Glacial waters could never have height inferior to the sea. By chance they might be near, slightly above, the sealevel. Usually they were a recognizable distance above the marine plane, the latter being determined by a variety of positive features over long distances and wide areas. A vertical interval with no, or very weak, deposits suggests the relatively sudden drop of the glacial waters to the marine level.

It is only the sand-plains or shore forms very close to the marine plane which are liable to confusion with the sealevel features. An example may be helpful.

Many years ago Professor Davis described the delta of the Catskill Creek, built in the Hudson estuary, at South Cairo, some 7 miles from the Hudson River (Coxsackie and Catskill sheets). The relation of the Catskill tributary valley to the Hudson trunk valley might permit glacial damming in the former. The South Cairo plains have every character and relationship of an estuary delta built in slowly subsiding waters. It may be conceded that we have no absolute proof that the Catskill waters

STREAM TERRACES: LITTLETON, NEW HAMPSHIRE

Three terraces appear on the south side of the valley. View from level of Main street, west edge of village. Work of the Ammonoosuc River when it was graded to the marine level. Altitude of the upper terrace, about 785 feet, the theoretic marine plane being about 735 feet.

were not glacial; but we do have the positive proof that an estuary occupied the trunk valley at the altitude of the Catskill delta, with a splendid bar at Hudson Village, on the east side of the open valley, at corresponding elevation (84, page 290). In practically every tributary valley on both sides of the Hudson-Champlain, from New York City to Canada, we find delta plains in precise agreement with the uptilted water plane of the open valley. Such correspondence in level in a multitude of independent water bodies would be impossible. Glacial deposits at higher levels are often recognized. The Catskill delta is simply one of very many estuarine features in accordance through 300 miles of uplifted territory. Most geologic reasoning is based on the kind of cumulative evidence which we have in this case.

It is possible that a few high-level features regarded by the writer as marine level may be glacial; but they are certainly exceptional. The deltas and shore features marking the stand of the sea on the depressed land occur in every one of the hundreds of valleys opening to the sea. In the tracing of the marine plane many features have been ignored because of some doubt.

TERRACES

It is important to discriminate the terraces formed in subsiding static waters from the benchings on stream-cut valley sides. That this has not always been done is shown by the reference of terraced estuary deposits to river work. The successive banks of rejuvenated streams may represent floodplains that were aggraded much above the highest static water level, both in horizontal and vertical distance. The genetic distinction is necessary for the clear recognition and close determination of the summit marine plane, although for long distances over the great uplifted area even the superior stream benches are useful in indicating approximate levels. The description of a typical example will illustrate the topic.

At Littleton, New Hampshire, the valley of the Ammonoosuc, a tributary of the Connecticut, is about one-fourth mile wide. Horizontal benches are conspicuous on both sides of the narrow valley. The main street of the village is on the north side main terrace. On the south side three benches occur, shown in the photograph, plate 9. These benches are partly erosional, cut in the till, and partly constructional as floodplain deposit. The constriction of the valley rules out efficient wave action. It is apparent that the river flow was up to the highest bench, some 10 to 15 feet above the railroad station, which is given as 772 feet, and that the lower lines were produced as the river fell in adjusting itself to a falling baselevel.

These aggraded river deposits are at least 60 feet higher than the estuary levels a few miles below at Barrett and Sugar Hill, and they extend upstream over a mile to Apthorp, where the plain is about 30 feet higher than at Littleton, being given as 814 feet.

Below Littleton the valley widens, with broad lateral embayments at the junction of the tributary valleys. In these embayments are high-level deltas, sculptured into terraces, which mark falling stages of the estuary waters. The summit planes at Barrett and Sugar Hill were estimated at 705 to 725 feet. The theoretic altitude, according to the isobases, is about 720 feet for the marine plane. That these terraces on the detached deltas are the work of standing water, combined with the depositional work of the inflowing streams, is perfectly evident. Terraces are limited to the deltas, with no benching of the till walls of the valley. The width and irregularity of the valley rules out river work. Precisely the same characters belong to the terraces of the Connecticut, Hudson, Champlain, and all the large valleys open to the sea.

Another point in way of discrimination may be noted. In the narrow river section of the valley there are no deltas at the mouths of the tributary valleys, as the contributed detritus was carried away by the trunk stream current. And the lines along the valley sides have a continuity and straightness impossible to weak wave action. On the other hand, the convex and irregular outlines of the delta fronts in the estuary section of the valley, with absence of erosion lines on the till salients of the valley walls, rule out river work.

To most students all this will seem very elementary and quite commonplace; yet the significance of these features appears not to have been recognized by those who regarded the high-level terraces of wide valleys as the work of enormously flooded rivers.

INITIAL WATER PLANE ON DELTAS

A heavy delta in a relatively narrow valley may be built far out in and beneath the static water and also be aggraded upstream far beyond and much above those waters. On these ancient "fossil" deltas we may have a horizontal extent of several miles and a vertical range of even 100 or 200 feet. Such is the character of many of the heavy deltas built by the glacial outwash and later land streams at the initial plane of the sealevel waters. The discrimination of the subaqueous portion of the primitive delta from the subaerial, aggraded part becomes important for the close determination of the earliest marine plane. In other words, the problem is to locate along the sloping surface of the delta the intersection of the initial or highest static water level of the estuary. A close determination

is not easy and often is impracticable, but there are some suggestive features.

The materials composing the subaqueous plain are finer and more uniform or better distributed than the subaerial or stream-laid deposits. They have a smoother and more nearly horizontal surface, and usually display a series of steps or terraces with definite cliff borders, produced in the subsiding waters. These are sometimes of such dimensions as to be indicated by 20-foot contours. A good example is seen in the lower left corner of the Glens Falls (New York) sheet. On the other hand, the upper aggraded part of the delta was affected only by the river flow and will have no transverse cliffs, though it may be cut by the rejuvenated stream into longitudinal steps or stream-banks. This suggests the importance of criteria for discrimination between wave-cut cliffs and stream-cut banks.

The subaerial part of the delta has more continuous, average upslope, the materials are more varied, and the surface locally more irregular, more likely to display stronger distributary channels in the course detritus. The lower reach of the cobble and the change to sand or finer gravel may be taken as the limit of unchecked flow.

As with most complex natural phenomena, it is easier to state theoretic distinctions than it is to apply them in the field. The determination of the initial marine plane on large deltas is only approximate and requires checking by the study of neighboring features. The best practice is to use the great deltas for approximate height, and then to make close determination by study of the small deltas of the lateral streams and of the shore features of the near-by valley walls.

In districts of great tidal range, like the Bay of Fundy, the determination becomes more a matter of judgment based on experience than in regions of steadier water level.

INFERIOR VALLEY PLAINS

The highest of the broad, conspicuous valley plains have sometimes been accepted as the summit level of the standing waters. When the stretches of open valleys, like the great valleys of New England, are in question this decision must always be an error. The only detrital plains that could be laid near the surface of the primitive estuaries must have been related to the headwater deltas or to the deltas of lateral valleys, and such plains were coarse materials—cobble, gravel, or sand—never silt or clay. The valley plains of fine material were either accumulated in considerable depth of water or as floodplains of an inferior level.

The greater thickness of the broad valley deposits is usually massive clay or silt and is capped by sand. The deep clays of the Hudson, Champlain, Connecticut, and other New England valleys are well known and are often 100 or 200 feet in thickness. W. A. Johnston says that in the lower part of the Ottawa Valley the clays have a vertical range of 600 feet (48, page 20). The occurrence of finely laminated clay and silt is proof of a higher surface of relatively quiet water. The depth is variable, according to variant combination of factors; but the least depth noted by the writer is at Bradford, Vermont, where, in the valleys of Waits River and Mink Brook, the clay reaches up to within 60 feet of the theoretic and the measured water surface. At Ottawa City the land uplift is about 700 feet and the clays lie at 600 feet.

In his monograph on the glacial gravels of Maine, previously noted, George H. Stone makes special mention of the clays. Like the Hudson and the Connecticut, the deep valleys of Maine afford good examples of the fiord or estuarine character. And as the valleys open directly southward to the sea there can be no doubt of the nature of the flooding. Concerning the valley plains, Stone writes:

"The hypothesis that there was a greater elevation of the interior than of the coast region of Maine helps clarify some heretofore very doubtful points of interpretation. At elevations extending from 350 to 450 or 500 feet are plains of valley sediments up to 5 miles in breadth, and in a few cases they are somewhat wider. If these great sheets are valley drift, they demand very large rivers. But if they are in large part marine beds—that is, fluviatile deltas formed offshore in bays or fiords—we do not need so large streams to account for them" (page 488).

"Below Moscow and Bingham the sedimentary plain of the Kennebec is from 1 to 6 or 7 miles wide" (page 489).

Concerning the clays, Stone says:

". . . For instance, a nearly continuous sheet of clay extends from the sea up the valleys of the Kennebec and Sandy rivers to a height of 450 feet or more" (page 56).

Stone's map of the marine clays (his plate 2) makes the clay extend up the Penobscot Valley to the isobase of 500 feet uplift and up the Kennebec Valley to the 650-foot line. This implies a depth of 200 feet of water over the northern Kennebec clays.

The mistake in regarding the wide silt plains of the broad lower valleys as indicating the earliest water planes was probably due to mental prepossession of the theory of small land uplift or none at all. Like other features in the valleys, these plains have no satisfactory explanation except by deep submergence.

ABSENCE OF MARINE FOSSILS

The entire absence of marine fossils in the higher sand-plains and throughout some valleys has been sufficiently explained in former writings. Only fresh water existed in the Hudson, Champlain, and Saint Lawrence valleys until the ice-front receded from northern New Brunswick and Gaspé Peninsula. Then salt water passed up the Saint Lawrence Valley; but by that time the wave uplift had raised the lower Hudson district to something like its present height, and the primitive and highest sealevel shoreline was lifted much above the marine waters. W. A. Johnston says that marine fossils do not occur above 510 feet in the Ottawa district (48, page 27). This is 190 feet beneath the uplifted marine plane.

Because of the free connection with the sea, marine fossils might be expected in the early deposits of the New England valleys. But the physical factors argue for unfavorable biologic conditions when the early deposits were laid. The waters in the broader, lower stretches of the estuaries must have been affected by the copious glacial flood added to the land drainage. The coarse detritus was piled near the mouths of the streams and only the deeply submerged clays could preserve the salt-water organisms. As the ice-front receded and uncovered the upper stretches of the estuaries, the constriction of the valleys increased the percentage of the fresh water. No marine fossils are found anywhere in the deposits near the summit water level, and they should not be expected.

Regarding fossils in the inferior deposits, Stone writes:

> "The fact that fossils are rarest where the clay is deepest proves unfavorable conditions for marine life near the mouths of both the glacial rivers and the ordinary rivers. In other words, the vast influx of ice-cold and muddy fresh water during the final melting of the great glacier was destructive of marine life.
>
> "The rarity of fossils contained in the upper clays and silts makes it very difficult to determine where the marine beds end and those of estuarine and fresh-water origin begin" (page 56).

Absence of marine organisms can never be taken as proof of nonmarine water or lack of confluence with the sea.

ABSENCE OF SHORE FEATURES

The lack of positive shore features even on long stretches of the old and uplifted shorelines is not valid negative proof. In production of shore inscriptions the principal factor is duration, and the rise of the land more or less promptly after the removal of the ice-load prevented concentrated attack by the waves not only at the initial level, but at all inferior levels.

On exposed coasts the tidal variation of the water level inhibited rapid production of shore features, while inland and along the entangled valleys wave action was too weak. Every experienced observer knows that over wide areas where it is certain that standing water existed for ages the surfaces today may show no clear evidence.

Apart from deltas the constructive shore feature is gravel bars. But their production requires a concentration of coarse material, with favorable conformation of the shore, and these conditions are rarely fulfilled apart from deltas or kames. A supply of well rounded cobble or coarse gravel is requisite to enable the waters, short-lived at any horizon, to pile the stuff into bars. They need not be sought on shores exposed to erosive action, and scarcely ever on sandy tracts, for reasons previously given (84, pages 299-301).

For erosion features perhaps no coast presented more favorable exposure than that of Maine. The comparative failure of wave-work there is shown by the following quotations from Stone:

> "At the higher elevation (on the islands of the coast) the surf had time to erode the till from the more exposed shores, but it had not time to form a cliff of erosion in the solid rock before a change of level transferred the wave action to higher or lower rock. In other words, the changes of level of the sea were relatively rapid" (page 44).
>
> ". . . The fact that those valleys of most uniform slope and exposure to the sea do not show well defined beach terraces proves that at least the fall of the sea proceeded at a nearly uniform rate, unless the pauses at 225 to 230 feet and 20 feet be exceptions" (page 53).
>
> "The fact that the till was only partially eroded from the outer islands proves that the retreat of the sea was geologically rapid" (page 486).

To limit the height of an upraised shore to the conspicuous beach features seen along a slope or valley side, or even to the outer deltas, will nearly always result in serious error.

VARIATION OF BEACH ALTITUDE

Shore phenomena may be quite unequal in height, even when made in identical water level, on account of variation in the factors or combination of factors concerned in their production. These variables may be noted as (1) tidal range; (2) different exposure to winds and storms; (3) slope, conformation, and character of the shore; (4) topography of the neighboring coast; (5) character and volume of the detritus; the latter related especially to (6) stream contributions or deltas.

The variation that an observer might find within a mile might be 10 or 15 feet, particularly in comparing bars and cliffs. Even along a continuous bar a difference in the crest height may be 5 feet in a short distance.

For the above reasons very precise determination of water levels, to the exact foot, is usually impracticable, and is possible only by detailed and intensive study over some distance, and even this is an average. Of course, it is understood that deformation must be expected on lines that cut the isobases. Thus it becomes necessary to discriminate clearly between beach variation due to variables of the shore and that due to land tilting.

The Map

The map of isobases, figure 1, shows the total post-Glacial uplift, which is all of Wisconsin or post-Wisconsin time, except possibly territory west of Ohio and Michigan. The map published as plate 10, in volume 27 of the Bulletin of the Geological Society, is confirmed in essential features by all subsequent study and constitutes the nucleus of the present map. The chief modification of the former map is the slight curvature given to the isobases in their extension over the greater area. For example, Ottawa City here lies on the 700-foot isobase, while with the direct lines of the former map it lay at about 730 feet.

These isobasal lines are drawn in three forms or degrees of reliability. The heavy solid lines are quite positive, being located by clear evidence of the summit sealevel waters. The light solid lines are approximately correct, based on suggestive data and their position being necessitated by the relationship and control of the heavy lines. The broken lines are more or less hypothetic, but the only lines which are wholly theoretic are the extensions of the isobases of zero to 500 feet over Indiana, Illinois, and Wisconsin.

The map strongly indicates the causal relationship of the ice-caps to the Pleistocene diastrophic land movement. The uplifted area shown by the isobases is also the glaciated territory. The glaciers deployed on the land to thin borders, but where the sea was reached the more rapid melting and erosion limited the extension of the ice-sheet. In other words, on the land the ice extended farther from its gathering ground or alimentation area than it did on the oceanic spaces. In consequence the flow was more rapid and the surface gradient was steeper along the radii toward the marine borders.

In the Mississippi Basin glaciation extended to the Ohio River, and, judging from the apparent relation of land movement to glaciation over the greater area, it would seem probable that this region should have suffered some movement. As the Mississippi Basin was occupied by ice-sheets antedating the more easterly Labradorian glacier, and with greater reach to the south and southwest, it is possible that the early unloading

of the southwestern border permitted some rise in the district previous to the waning of the Labradorian sheet. It is therefore probable that the differential uplift shown in the glacial lake beaches of the Michigan and Erie basins is not a record of the earliest nor the total uplift in the western area. The wavelike uplift of the earth's surface following the re-

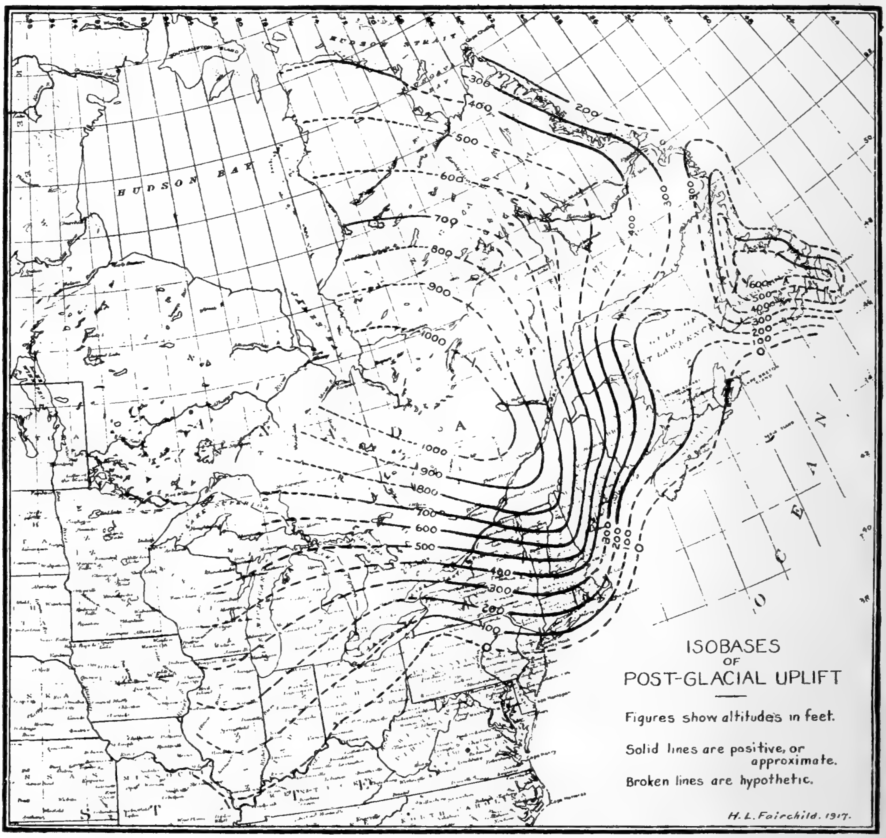

FIGURE 1.—*Post-Glacial continental Uplift*

The lines indicate, in feet, the amount of land uplift following the removal of the Labradorian ice-cap

moval of the ice-burden probably raised the territory southwest of the Michigan and Erie basins, at least in greater amount, before the lake inscriptions were completed.

The near horizontality of the southwestern stretches of the ancient beaches is not proof of lack of land uplift, because some reasonable relation of lake history to rise of land might leave the shorelines quite level.

Taylor's "Whittlesey Hinge Line," his zero of land uplift, lies 250 miles north of the ice limit of the Wisconsin stage and 350 miles north of the extreme glacial limit (80, figure 14, page 503), and it has no reference to the ice lobations. The thickness of the ice at this line was 3,000 to 4,000 feet (80, page 511). It would appear more probable that some combination of wave uplift with the lake history has left the southern beaches with small deformation than that such great thickness and extent of the ice had no diastrophic effect.

The map shows that the post-Glacial land uplift of northeastern America is fairly proportionate to the area and thickness of the latest ice-sheet, and it appears legitimate to suggest similar relation in the Mississippi and Great Lakes region. The southward curve given to the lower-value isobases may be excessive, but they suggest an uplift for which evidence should be sought.

It should be understood, therefore, that the isobases as extended in the Mississippi Basin are intended to be only suggestive of the southerly limit of the Pleistocene land uplift, and that the lines of the rest of the map, east of Michigan and Ohio, indicate the total rise of land during and following the removal of the latest, or Labradorian, ice-cap.

The location of the central area of uplift between Quebec City and James Bay agrees with the conclusions reached many years ago by J. W. Spencer, using a different method. He located the area of maximum uplift by triangulation on points of the deformed shorelines. As early as 1889 he summarized his conclusion as follows:

"At any rate, it is in the region southeast of James Bay that the maximum differential elevation of the earth's crust, which involved the Iroquois Beach, is to be found." [3]

And in 1913 he wrote as follows:

"By triangulating the Iroquois, Algonquin, and other beaches, the dome of the greatest deformation of the Great Lakes region is found to be situated approximately in latitude 50° 30′ north, longitude 75° west. This is confirmed by the course of the drainage of the highlands. It is the locality where the 'height of land' reaches its most southern lobe" (79, page 227).

The map also suggests that the latest ice-sheet on North America would more appropriately have been named from Quebec instead of Labrador.

Over Labrador the isobases have been adjusted with particular reference to Professor Daly's figures for the raised beaches along the northeast coast (39). His study seems to locate fairly the 300- and 400-foot

[3] Transactions of the Royal Society of Canada, vol. 7, 1889, p. 129. Journal of Geology, vol. 19, 1911, p. 57.

lines. Force is also given to some unpublished figures by Professor Coleman.

Professor Daly's altitudes for the east coast of Newfoundland are harmonized with the isobases of the mainland only by regarding the island as an independent area of depression of about 600 feet, which implies a separate ice-body. This carries the study over into meteorology.

Criticism may possibly be offered that the isobases in the map are too regular and parallel. Any irregularity in the direction and spacing that would appear on a map of this scale would be due to irregular uplift or local warping. Perhaps there is such in slight degree, but it would be attributed to, or confused with, the local variation in height of the shore features. However, the depth of terrane involved in the diastrophic movement would appear too great to permit any sharp or local warping of the surface, under either the hypothesis of compression and elastic reaction or the conception of deep-seated flowage. No recent faulting has been seen sufficient to produce any change in beach levels. The isobases as drawn are, of course, somewhat generalized, but they represent the facts in surprisingly accurate degree. The variations of the summit features from the theoretic height, as indicated by the isobases, are given in the tabulations below. These seem small when all the causes of altitude variation are considered, as described above.

Shorelines traced in the field and the isobases as drawn have no consideration for mountain mass or valley deficiency. Apparently the surficial relief of the continent had no measurable effect on the amount of uplift. This should be expected when it is remembered that the large topography was pre-Glacial and isostatic equilibrium had long been established.

The truth of the map is not dependent on the precision of a few stations, nor on the approximate figures for many stations, but on the general accordance of the field data with the adjusted isobases over the great area.

Whatever correction the future may make in this map is more likely to be in the increase of the amount of submergence and uplift, as we may have to recognize some rise of the ocean level after land uplift had begun, and also some lifting of the central part of the area while yet beneath the ice-sheet. The writer has been conservative and careful not to overestimate, and he has the feeling that he has sometimes committed, in smaller degree, the usual mistake of minimizing the height of the upraised marine plane.

Relation of Land Uplift to Ice Recession

This topic has been discussed in a previous paper (82, pages 249-252). It was there argued that the rise in the marginal areas of the glaciated territory could not begin until the ice-front was some distance removed; that the uplift was by a wave movement; and that the wave did not overtake the retreating ice-margin in the Hudson-Champlain Valley. Later study suggests that possibly the uplift wave did overtake the ice-front at the north boundary of New York; in other words, that there might have been a small amount of land rise beneath the thin edge of the ice-sheet while this lay against Covey Hill. The reasons for this are given in the detailed description of the New York features now awaiting publication.

Theoretically, it seems possible that while the nucleus of the Labradorian ice-cap, relatively small in area and much reduced in thickness, lingered in the cool climate of the Laurentian highland some uplift affected that ice-buried area. Whatever rise of the land took place while it was yet covered with ice would not be recorded by aqueous deposits. This conception suggests that the isobases for the central part of the glaciated region may represent only the later portion of the uplift. The study of this matter is bequeathed to the future. In this paper it is not practicable to consider the geophysical problem of diastrophism as related to glaciation. A recent discussion of the subject by Taylor is to be found in the paper listed as number 80, pages 508-518.

Change in Ocean Level

The Pleistocene ice-caps consisted of water withdrawn from the ocean. The total mass of the several ice-sheets represented an enormous volume of water, and if the continental glaciers were contemporary the reduction in the level of the ocean was considerable. Even the Labradorian ice-sheet alone must have changed the sealevel. On northern coasts this lowering of sealevel was in some small amount counterbalanced by the gravitative effect of the ice-caps. When the ice-caps melted, the water was returned to the sea and the original level restored. Estimates have been made to the effect that in the equatorial zone the seas were lowered about 200 feet (41, 42).

Evidently this is a complicated problem, involving many meteorologic, geologic, and geophysical factors; and especially difficult when applied to the closing stage of the latest North American glaciation, with its elements of uncertainty. Without attempting any serious discussion of

this extremely difficult, but interesting problem, the altitude relation of the hypothetical change of water level to the post-Glacial land uplift may be briefly outlined.

Assuming an effective rise of the ocean level, due to the return of the glacier water to the sea, the following conditions seem imperative or highly probable:

1. The rise of ocean level (flooding) was proportional to the waning of the glaciers, and was contemporaneous, not subsequent.

2. In at least the peripheral portion of the uplifted area the rise of the land was subsequent to the removal of the ice (unloading) from such area.

3. The land uplift was by a progressive wave movement.

4. Toward the center of the glaciated area the wave of uplift might have overtaken the slowly receding margin of the diminished ice-body, so that some uplift occurred beneath the ice-sheet while the sea was yet excluded from the district, the sea being nearly restored to full height.

From the above conditions the following conclusions are derived:

(*a*) About the borders of the uplifted area, where the rise was small, diminishing to zero, and where the ocean flooding was the maximum, the primitive shore features are all submerged.

(*b*) The primitive marine shore features at any point are now above the present (flooded) sealevel only where the total land uplift has exceeded the rise of the ocean, which occurred subsequent to the beginning of the uplift at that point.

(*c*) Therefore the total land uplift at any point is the present apparent and measurable height above the sea plus the vertical amount of ocean flooding subsequent to the initiation of land uplift at that point.

The above conclusions may be restated in the following generalizations:

(A) Except at the center of the uplifted land area, the total amount of land uplift is everywhere greater than the apparent rise.

(B) The amount of marine flooding is maximum at the periphery of the glaciated area and declines to zero at the center.

(C) Conversely, the apparent or visible uplift, like the total uplift, is greatest at the center of the area and diminishes toward the margin.

The immediate practical application of the above conclusions may not be unimportant. As the datum level for all land uplift is the present sea surface, it is not feasible to determine the amount of non-apparent or flooded rise of the land; but the relation of the apparent uplift to the glaciated borders, as indicated by the map, may be significant.

The only locality east of the Hudson Valley where the terminal moraine lies on the land is Long Island. At the middle of the Island the

uplifted marine shore is 100 feet above tide. With this amount of visible uplift at the limit of latest glaciation, it would seem either that the rise of ocean level had been small or that the uplifted area extends far out under the sea and much beyond the loaded area.

Nova Scotia was wholly glaciated. Multitudes of huge erratics are piled along the southeast shore and in the harbors (plate 17); but part of the south shore exhibits no uplift (see the zero isobase of the map). Either there has been no uplift here or else the flooding of the sea has exceeded the uplift.

On the coast of Maine the ancient beaches are from 200 to 400 feet above tide. At Saint John, New Brunswick, the uplift is 200 feet. On the east coast of Newfoundland the apparent uplift is even greater, being at Saint John, according to Daly, about 575 feet. It appears probable that the independent Newfoundland ice-cap spread widely beyond the present shores, yet 575 feet seems a large amount of rise if some non-visible rise is to be added.

It should, however, be emphasized that no changes of sealevel, by whatever cause, can account for the great differential elevation of the shore features found in passing inland, rising from zero at Yarmouth and Sydney to over 1,000 feet northwest of Quebec City.

Tabulation and Description of New Data

GENERAL DISCUSSION

In the column of "definite" altitudes are placed only those measurements which were taken on fairly clear features. The observations which were uncertain, either for lack of time or lack of good datum or for poor behavior of the aneroid, are placed in the other columns. The range of error for the definite figures will usually lie within 5 or 10 feet. No figures are placed in that column which are not regarded as correct within 5 feet.

In many cases the altitude is quite precise and subject to no serious change. The sources of error are: (1) wrong figures for the railroad elevations, which were chief datum for most of the area in Canada and for some territory in New England; (2) the variation of aneroid, which was usually checked and corrected; (3) the uncertainty of the contours of the older topographic sheets, where no precise altitudes are given except the useless hilltops. A coincidence of errors is as likely to neutralize as to magnify.

The chief uncertainty in the study arises from failure, due to lack of time or want of good altitude data, to determine closely the initial

water plane on some of the larger deltas. In some cases instead of a definite figure the two figures for the vertical range within which the plane lies are given.

While more intensive study will change some of these figures, the writer is confident that the future will confirm the general accuracy of the figures in the column of theoretic altitudes.

It will be noted that the figures are usually in multiples of 5. It is not now practicable to make the theoretic figures more refined, although it may be so eventually, and for the measured altitudes it is unnecessary to take time and give labor to secure precision to the foot when there is so much variation in the height of shore feature, as previously described.

HUDSON-CHAMPLAIN VALLEY

The altitudes of the shore features on the marine plane in New York, including Long Island, have been partially given in previous papers, listed in the appended bibliography as numbers 81-85. The detailed description of the closing Pleistocene of New York State, giving altitudes of the features in the Hudson, Champlain, Saint Lawrence, and Ontario valleys, is awaiting publication. The shore features on the Vermont side of the Champlain Valley are described in paper number 83.

WESTERN NEW ENGLAND

For the State of Connecticut, verified altitudes are limited to the Connecticut River Valley.

For Massachusetts, the figures given by Emerson (64, 65) for the static water levels ("Connecticut Lakes") in the Connecticut Valley are regarded as precise. Some of them have been personally verified, especially for the 400-foot isobase.

The streams tributary to the Connecticut River afford interesting opportunity for this study, care being taken to discriminate the sealevel deltas from the glacial water deposits. An example is found at Shelburne Falls, on the Deerfield River. Under the village and northward are handsome gravel plains rising to 428 feet, but the isobase of the locality is about 375 feet. Some of this superior altitude might be attributed to aggradation above the static water plane; but more probably these high plains represent glacial ponding, by the lobation of the ice-margin in the Connecticut Valley. The marine delta has probably been destroyed by the river erosion in the narrow valley, although some remnants should be found. The true plane of the ocean-level waters may be determined by careful study of the sides of the Deerfield Valley below Shelburne Falls.

COBBLE DELTA: BARTLETT, NEW HAMPSHIRE

Summit of delta of Razor Brook, built in the sealevel waters of the Saco Valley. One and one-half miles northwest of the village. Altitude, 725 feet, and graded 20 feet above the marine plane. Looking northwest.

For Vermont some new data is given below, description of the details being reserved for the report of the State Geologist. At Bradford massive clay reaches up to 600 feet, to within 50 of the summit sand-plains. The features here, as at many other points in the valley—Brattleboro, White River Junction, Norwich, Lewiston, and Hanover, New Hampshire—are on the sides of the open Connecticut Valley, with no relation to any possible glacial waters by lateral ponding.

In New Hampshire several localities have been examined with definite results. Good bars and other features along the south side of Lake Winnepesaukee definitely locate the 600-foot isobase. Through the Saco Valley the sealevel waters reached into the White Mountains as far as Bartlett, where clear features are found south, west, and northwest of the village (see plate 10).

Eastern Massachusetts and Rhode Island have not yet been examined by the writer. Most of the area is beneath the summit marine plane, as shown by the topographic sheets, but a few hills should preserve records of the highest wave-work, and a few streams from higher ground will probably exhibit the summit deltas. The topographic sheets lack sufficient relief expression to indicate the summit sand-plains. As a whole, the region must be difficult for this study, one proof of which is the failure of students to recognize the initial or summit marine level. Probably the delta plains, which have been attributed to glacial waters (70, 71, 73, 75), were mostly built in the lower levels of the marine waters. The fine succession of sand-plains in the Sudbury Valley described by Goldthwait (75) is the condition to be expected in the slowly falling marine waters, but is very unusual in glacial lakes. The later level of Crosby's glacial waters in the Nashua Valley (370 feet) probably represents the summit marine level.

Altitudes of the earliest and highest Marine Levels

Location.		Theoretic altitude by isobases.	Observed altitudes.		
Stream valley and station.			Definite.	Approx.	Minimum.
MASSACHUSETTS					
Deerfield River	Shelburne Falls	375	...	...	...
Connecticut River	Northfield and East Northfield.	430	400	...	...
(See Emerson's papers)					
Millers River	Farley	385	...	380	365
North Nashua River	Fitchburg	395	...	400	...

Location.		Theoretic altitude by isobases.	Observed altitudes.		
Stream valley and station.			Definite.	Approx.	Minimum.
VERMONT (CONNECTICUT VALLEY)					
Whetstone Brook	Brattleboro	420	...	425	...
West River		...	...	...	...
Saxtons River	Saxtons River villag	475	...	...	465
Williams River	Bartonsville	485	...	...	480
Black River		...	...	...	...
White River	Randolph-Bethel	600	...	630 600	...
	White River Junction	575	570	...	...
Bloody Brook	Lewiston-Norwich	590	590	...	...
Ompompanoosuc River		...	...	...	...
Waits River (Brushwood Creek)	Bradford	650	660	...	...
Mink Brook	Bradford	650	650	...	...
Wells River	Boltonville	680	...	690	...
Passumpsic River	Lyndonville	750	...	740	...
NEW HAMPSHIRE (CONNECTICUT VALLEY)					
Mill Brook	Granger Hollow	445	...	440	...
Sugar River	Claremont	515	530 510	...	...
Mascoma River	Lebanon	575	575	...	...
Mink Brook	Hanover	590	585	...	...
Oliverian Brook	Haverhill	670	...	675	...
Ammonoosuc River	Sugar Hill-Barrett	720	...	720	...
(Merrimac Basin)					
Souhegan River	Wilton	440	440	...	...
Contoocook River	Henniker	500	...	500	...
Warner River	Roby	525	...	530	...
Lake Winnepesaukee	Alton Bay-Alton	590	...	...	580
	Beaches, Smith Point	600	600	...	...
	Beaches, Terrace Hill	665	610	...	...
Bakers River	Wentworth-Swainsboro	630	...	675 585	...
Pemigewasset River	W. Thornton-Woodstock	670	...	675 650	...
(Eastern border)					
Cocheco River	Davis-New Durham	555	...	...	535
Salmon Falls River	Sanbornville	575	575	...	...
Saco River	Bartlett	700	705	...	...
Androscoggin River	(See Maine)	...	...	...	...

MAINE

Maine, the fiord State, is mostly low-lying and a large part was beneath the sea when the ice-sheet melted. Deep valleys—the Androscoggin, Kennebec, and Penobscot—extend north at submarine levels through more

than half the State, and the Saint John Valley forms the north boundary of the State, with elevation far below the summit marine plane. The most obtrusive features of the State are the extensive clay and silt plains laid down in the oceanic waters. There can be no suggestion of glacial waters in the broad south-leading valleys.

The curving isobases lie northeast and southwest across the State, cutting the drainage obliquely, thus giving long stretches of the great valleys with low gradient of the marine plane. The main valleys were mostly too low to receive the summit deltas. The Saco River has its high delta at Bartlett, New Hampshire, in excellent form. The Androscoggin marine summit is at Bethel, where it has been carefully studied and discriminated from the aggraded and probably glacial filling at Gorham, New Hampshire, and northward. The Kennebec is rather exceptional, in having at the early marine level a narrow, canyon-like valley unsuited to the preservation of delta deposits, but at Bingham and southward the inferior plains are conspicuous. The Penobscot Valley proper is all low and the initial deltas are in tributary valleys in unmapped territory. The Saint Croix heads in a series of lakes and has no summit delta, although the marine gravels occur at Vanceboro and Saint Croix, New Brunswick, at about 400 feet. The only part of the Saint John Valley that was above the ocean is the north-leading section, heading southeast of Quebec City, all in wild country with no known altitudes.

George H. Stone recognized the deep submergence of Maine (68), and great weight must be given his conclusions, based on long, careful, and discriminating study. From the following quotations (the italics are mine) it will be seen that he was conservative as to the amount of oceanic submergence, probably in deference to the prevailing American opinion, although he had a leaning to more radical views. Concerning the marine beaches on the coast of Maine, he writes:

"I then went nearly around the island (Isle au Haut) at this elevation (225 feet) and at every valley found rounded gravel and boulders up to 225 feet. at which elevation the rolled gravel began to thin out, and the contour of 250 feet was plainly above the water-washed drift" (page 48).

Of the hills three miles north and northeast of Machias, he says:

"At 220 feet the top of a terrace of rolled gravel and cobbles was observed. . . . This terrace is from 10 to 30 feet wide and is a prominent feature of the hillside. The gravel becomes thinner above the terrace—a sort of sheet overlying the till. Rolled stones could be found here and there at 240 feet. At 250 feet only ordinary till stones could be found, and from this point upward the hillside was searched for almost a mile, only till being found" (page 49).

". . . The average of these and many similar measurements, with a good

aneroid, gives the height of the highest beach near the outer coastline as about 225 feet for the region east of Penobscot Bay and 230 feet for the region between that bay and the Kennebec River" (page 49).

". . . *Since the height of the sea rapidly diminishes southward in New Hampshire and Massachusetts,* it appears that the average elevation of the sea on the Atlantic coast south of Nova Scotia was greatest in the region lying between Portland and the Penobscot Bay, or perhaps near the mouth of the Narragaugus River" (page 50).

A glance at the map of isobases will show that the figures of Stone for the marine submergence on the Maine coast are in practical accord with the new data of the map. He underestimates the difference in uplift between the shores east and west of Penobscot Bay, but correctly determined the inclinations, as shown in the last of the above quotations.

Concerning the interior sand-plains, he writes in his summary:

"4. Elevation of marine deltas.—The deltas of the interior at 300 to 350 feet are now interpreted by me as marine, but possibly this point may be disputed. They certainly do not bear such relations to the fossiliferous clays as the deltas nearer the coast. But sheets of clay and sand are found extending from the deltas up to considerably higher elevations, *and therefore under no conditions do the deltas mark the highest level of the sea.* . . . The higher deltas are more than 100 feet above the highest fossil thus far found. . . . Both together constitute valuable collateral evidence of the presence of the sea in the interior valleys, *but do not give the extreme limit*" (page 482).

"Some of these basal fine sediments pass above any level of the sea that now appears admissible, . . . *remembering that the subsidence in northwestern Maine was three or four times that of the coast,* or, rather, that the postglacial elevation has been such" (page 485).

"While we do not know the amount of early glacial subsidence, *we do know approximately the amount of postglacial elevation.* I assume that this elevation has been about three times as great in northwestern Maine as at the outer coastline" (page 486).

Stone's "assumption" of the relative uplift was based on good observation and correct philosophy. The isobase of 800 feet along the northwest boundary of the State is about three times the elevation of the portion of the coast which he describes, or four times that of the eastern coast.

In 1889 Professor Shaler published his description of Mount Desert (57). His long experience in the study of shorelines and wave action was applied in the work on the uplifted beaches on the island, with the conclusion that evidences of wave-work appeared up to a height of 1,300 feet (page 1032). His description of the features proving recent submergence are given with perfect confidence, and appear conclusive to the reader, for heights up to 250 or 300 feet (pages 1015-1022). Above this altitude his statements are qualified and the explanations and conclusions

not convincing. It is quite certain that he misinterpreted the higher features, unless, as he suggested, there had been very deep submergence previous to the latest glaciation. In this case we should expect that the evidence of wave erosion of rock slopes would be removed or masked by the subsequent ice-work. The brief duration of wave action on the rising land following the removal of the Labradorian ice-sheet would scarcely leave any traces on granitic rocks. The better method of locating the weak summit wave-work is by examination of drift-covered slopes, like the work of Daly in his study of the Labrador coast (39, pages 246-261) or that of Stone on the Maine coast (page 211 above).

When such a brilliant geologist as Professor Shaler, with his long experience in the study of seashores, found evidence of wave action at inadmissible altitudes, perhaps other men should be pardoned if they see none at all where it really occurs. Again, this emphasizes the difficulty in the study and the large psychologic element involved.

A traverse of the State was made and the fact of deep submergence fully attested, but time did not permit of the travel necessary to determine the summit marine level at many points. The isobases are adjusted in agreement with data westward in New Hampshire and eastward in New Brunswick and with Stone's figures for the coast. The theoretic figures in the following table are subject to change by 5 or 10 feet, depending on the curvature given the isobases. It is desirable to determine accurately the summit level at a few stations scattered through the State, and as a help in this study the approximate theoretic figures are given for a number of towns.

Altitudes of the earliest and highest Marine Levels

Location.		Theoretic altitude, by isobases.	Observed altitudes.		
Stream valley and station.			Definite.	Approx.	Minimum.
Saco Valley	Buxton	525	...	...	...
	Cornish	600	...	...	...
	Brownfield	630	...	...	...
Ossipee Valley	Kezar Falls	605	...	...	...
Portland City		495	...	...	...
Androscoggin Valley	Lewiston	570	...	...	...
	Bethel	715	720 710	...	...
	Gorham	750	800 700	...	...
Kennebec Valley	Augusta	525	...	...	...
	Waterville	535	...	...	...
	Skowhegan	575	...	...	...
	Bingham	645	...	...	...
Penobscot Valley	Bangor-Orono	435	...	...	...
Piscataquis River	Dover	560	...	...	...
	Kingsbury-Parrot	610	...	...	...
Pleasant River	Brownville Junction	560	...	...	...
Mattawamkeag River	Mattawamkeag	500	...	...	...
	Danforth	465	...	...	...
East Branch	Ashland Junction	555	...	...	...
Saint Croix Valley	Vanceboro	395	...	410	...
Saint John Valley	Van Buren	595	...	...	...
	Fort Kent	675	...	...	...
	Saint Francis	700	...	...	...
Atlantic coast (G. H. Stone).	Isle au Haut	250	...	240	225
	North of Machias	250	...	245	240

UPPER SAINT LAWRENCE AND OTTAWA VALLEYS

The evidences of salt water at high levels and of standing water at yet higher levels are profuse in the Saint Lawrence Basin. These features have been the subject of study, especially by Chalmers (see the list of writings). Most of the figures for occurrences of marine fossils and the height of delta sand-plains are of value as minimum altitudes, and some data are in close accordance with the theoretic altitudes. But glacial and marine deposits were not discriminated; the summit features were not clearly distinguished from inferior features, and the direction and amount of land tilting or differential uplift was not determined. This lack of discrimination and of correlation over wide areas produces discordance in the published data and makes them inconclusive. These

early writings are interesting and suggestive and of confirmative value. The latest and quite conclusive data for the district of Ottawa City are given by W. A. Johnson in two recent papers (47, 48). He finds marine fossils up to 510 feet and laminated clays to 605 feet. He gives the highest marine beach as 690 feet, and thinks that this represents de Geer's shoreline of 705 feet. In company with Director McConnell, Mr. Joseph Keele, and Mr. L. H. Cole, the writer spent one and a half days on the marine features of the Kingsmere Mountain and the lower Gatineau Valley, and would raise Johnson's figures by 10 feet. Good terraces lie at 700 feet, while broad silt plains at inferior levels imply some depth of water.

The occurrence of salt-water fossils at 510 feet leaves 190 feet barren toward the summit plane. This is to be expected, as marine life did not penetrate the upper Saint Lawrence region until the glacier front weakened on the highland of Maine and New Brunswick and gave confluence of water with the Gulf of Saint Lawrence; but before that even occurred and the marine organisms had penetrated to Ottawa considerable land uplift had taken place.

The contour of 700 feet is laid along the Ottawa River through Ottawa City and the village of Mattawa, which carries the marine plane to Lake Nipissing with altitude about 660 or 670 feet. This altitude is the height of the sand-plain at North Bay village.

The valleys declining northward or northwestward toward the great Saint Lawrence probably hold high-level glacial fillings, but these must usually correlate with the headwater cols or very high outlets, and by careful study should be discriminated from the marine deposits. The Chaudiere is the largest of these north-sloping valleys and holds very conspicuous terraces. Chalmers' altitudes for these plains, 800 to 900 feet, are suggestive; but it should be noted that the marine levels northward (down the valley) must be higher than those at the head of the valley.

In company with Mr. Keele, an examination was made of the slopes and summit of Mount Royal, at Montreal, with the conclusion that it had been vigorously wave-swept to the summit. The altitude is given as 763 feet, which leaves 50 to 75 feet of water over the summit.

LOWER SAINT LAWRENCE AND GASPÉ PENINSULA

The lower walls of the Saint Lawrence Valley, especially below Quebec, exhibit remarkably smooth convexity, due to possible repeated glaciation and certainly to recent submergence and wave action. The slopes show a surprising absence of small streams and postglacial ravines.

Reports on the marine levels have been made by Chalmers and Goldthwait. Examination of several districts has been made and the writer is convinced that the published figures are far under the true summit level. The conspicuous terraces and shore features and gravel bars on the deltas, which have been regarded as initial or summit features, are much inferior. The summit deltas of the streams are far inland in the deep valleys and have not been reached or are unrecognized as sealevel deposits. Positive shore features, even in the open valley, have been located by the writer at altitudes above any published figures.

The tributary valleys on the north side of the Saint Lawrence give no excuse for any question as to glacial water levels. It is unfortunate that east of the Saguenay (Tadoussac) the north slope of the great valley is so inaccessible and all in forest. The south-flowing streams must have left good bench-marks of the summit sealevel. Passing up the Batiscan River, on the railroad from Quebec to Lake Saint John, good delta plains are found up to 1,010 feet, and over the height of land near Roberval at more than 1,000 feet. These levels give approximate location for the contour of 1,000 feet. The only features which are not in accord with the map are the terraces of a heavy delta at Sainte Marguerite, some 40 miles northwest of Montreal. The theoretic marine level is here about 880 feet, but the delta plain at the railroad station is 970 feet, with other terraces in view 10 to 15 feet higher. There is some complication here which study will probably explain.

The north wall of the Saint Lawrence Valley between Quebec and Tadoussac, especially in the district of Saint Irénée and Murray Bay, exhibits conspicuous and unmistakable terraces and water lines up to 800 to 900 feet, seen from the river steamers. At Murray Bay these standing-water inscriptions were measured with aneroid up to 785 feet, and others appeared in the distance as much as 100 feet higher.

The south (southeast) wall of the valley was examined from River Ouelle to Mont Joli, with satisfactory evidence of high-level waters, but without definite measurements. One of the most convincing features is a remarkably extensive delta south of Trois Pistoles, with such extent and relation to the general topography as to rule out glacial waters. In this great delta the massive clay reaches up to 450 feet, with broad plains at 500 feet and higher terraces in distant view, estimated at 200 feet more. The theoretic summit level here by the adjusted isobases is about 715 feet (plate 11, figure 1).

Over the divide, in the southward drainage of Saint John River, is Lake Temiscuata, an expansion of Madawaska River. By the south side of the lake at Cabano station are two heavy gravel bars with altitudes 575

FIGURE 1.—ERODED DELTA PLAIN: TROIS PISTOLES, QUEBEC

View from point four miles southwest of village, looking south from a lower terrace; the 500-foot level. The summit level in the distance must be over 715 feet.

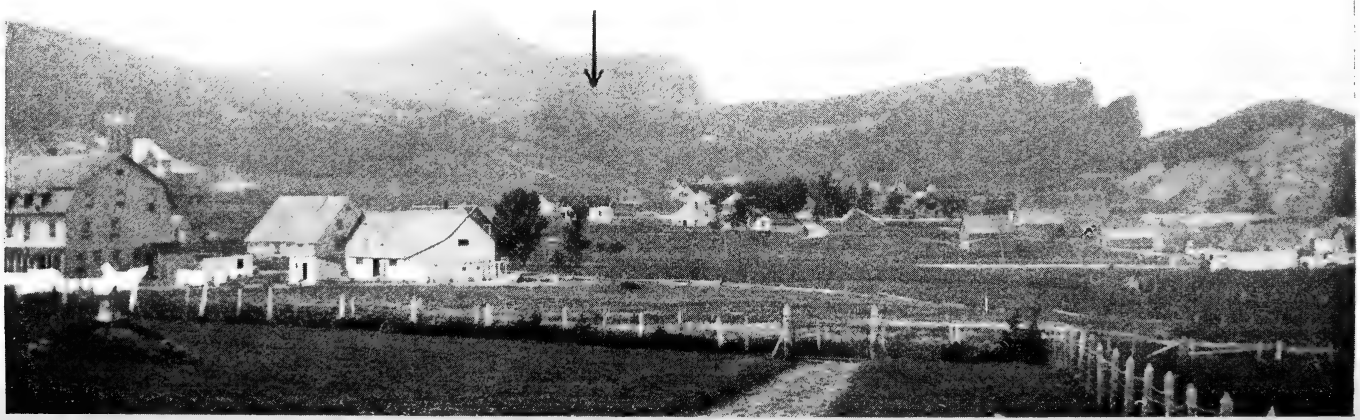

FIGURE 2.—MARINE DEPOSITS: PERCÉ, QUEBEC

View looking northwest over the village. The arrow indicates the detrital filling at near the summit marine level, here 225 feet.

SEA CLIFF: CORNER OF THE BEACH, GASPE, QUEBEC

Looking west from the east edge of the village. Altitude, 85 feet. This cliff correlates with the gravel bar, shown in plate 13, and with other strong features in the region. The uplifted marine summit here is 225 feet.

and 608 feet. Water work on the slopes west of the village was seen up to about 655 feet. The theoretic height here is 700 feet or a little more. The Matapedia River, flowing to Chaleur Bay, has left as fine display of declining delta plains as any valley can show. These head at about 600 feet and fall to sealevel. The extensive, smooth plain at Sayabec, 581 feet, is taken as the marine level.

The south shore of the Gaspé Peninsula, from Matapedia to Gaspé village, displays a profusion of elevated shore phenomena in beach lines, terraces, and sand-plains. These are conspicuous from the railroad, lying high on the northern and western slopes. Glacial waters were here impossible.

The minimum figures in the tabulation for the shore south of Percé are eye estimates, using the hand level from railroad elevations. From Percé to Gaspé the figures are reliable measurements, with the checked aneroid from sealevel or from the railroad stations.

Between Douglastown and Barachois are a series of streams the deltas of which form a wide plain, broken by the present ravines, which gives the railroad a long stretch of track at or near 215 feet altitude. The summit level of the deltas is above, west of, the railroad. This can readily be measured and will undoubtedly give very precise figures for the initial marine shore.

Between Percé village and Corner of the Beach, by the short road, are several detrital fillings in the valleys, with some good, but inconspicuous, gravel plains at 225 to 230 feet, and at least one good bar crossing the highway at 225 feet (plate 11, figure 2).

The most conspicuous ancient shore feature at Corner of the Beach is the massive bar and the sloping beach west of the village at 85 feet altitude. A strong terrace beach at the same height is conspicuous at and west of Gaspé village (plates 12, 13, and 14).

At Gaspé the slopes above the 85-foot bench exhibit effects of wave action, but the summit level is not apparent. However, this was found about two miles west of the village, along the "west portage road," in the pass between the two bays. Here are clear evidences of standing water up to about 240 feet. The features, small deltas and smoothed slopes, are positive up to 235 feet and seem lacking at 250 feet. Since these figures were noted it is found that they agree with Chalmers' determination. In his report, number 8 in the appended list, page 22 M, he gives the altitude at Gaspé Bay 225 to 230 feet and repeats the figures in his report 10, page 15 J. In number 16, page 254 A, he gives the limit of Pleistocene submergence at Gaspé as 240 feet.

The part of the Saint Maurice River valley followed by the Transcontinental Railway and its south-leading tributaries will give the deltas of the marine summit without glacial complication.

In the valley of Jacques Cartier River extensive inferior plains occur at Valcartier, and at Saint Raymond, in the Saint Anne River valley, is a very handsome display of terraced plains, also of inferior levels, as should be expected of such wide-spread deposits. The deltas of the summit level will be found northward in these two valleys.

Lake Saint John, with its fertile surrounding territory, lies very low, only 341 feet above tide. The valley must have been submerged about 660 feet, and the extensive detrital plains which have been noted by Chalmers and others up to height of 700 feet are much below the marine summit. The rivers, with the long names, flowing into Lake Saint John from the northwest will undoubtedly give the approximate marine summit without complication of glacial waters.

GRAVEL BAR: CORNER OF THE BEACH, GASPE, QUEBEC

At east edge of the village, looking southeast from the English church. Altitude, 85 feet. Correlates with the cliff, plate 12.

WAVE-WASHED SLOPE: GASPE VILLAGE, QUEBEC

South side of the harbor. Correlates with the strong inferior level of 85 feet. Characteristic slope of the lower levels. The summit marine plane here is 240 feet.

Altitudes of the earliest and highest Marine Levels

Location.		Theoretic altitude by isobases.	Observed altitudes.		
Stream valley and station.			Definite.	Approx.	Minimum.
Ottawa Valley	Ottawa	700	700	...	...
	Mattawa	...	...	700	...
	North Bay	675	...	680	...
West River	Lachute, northwest	825	...	...	795
North River	Sainte Marguerite	880	...	...	...
Saint Francis River	Sherbrooke	855	...	...	...
Chaudiere Valley	Tring Junction	885	...	880	...
	Saint George	855	...	...	...
Saint Maurice Valley	...	...	...	...	...
Batiscan River	Linton Junction	1010	...	...	906
	Linton Junction, northward.	1010	...	1010	...
Saint Anne River	Saint Raymond	970	...	...	810
Jacques Cartier River	Valcartier	950	...	...	...
Lake Saint John	...	1000±	...	...	...
Madawaska Valley	Cabano	700	...	...	658
Matapedia River	Sayabec	580	585	...	...
Saint Lawrence Valley	Montreal	840	...	...	763
	Quebec	925	...	...	...
Montmorency River	Laval	940	...	...	...
	Chateau Richer	925	...	...	835
	Saint Anne de Beaupré	920	...	...	660
	Murray Bay	850	...	...	785
	Tadoussac	800	...	...	400
	River du Loup	775	...	...	435
	Whitworth	750	...	...	720
	Trois Pistoles	740	...	...	500
	Saint Fabian	700	...	...	680
	Rimouski	665	...	...	...
	Little Metis Station	605	...	...	570
Chaleur Bay and Saint Lawrence Gulf.	Nouvelle	405	...	...	360
	Carlton	390	...	...	350
	Maria	380	...	...	355
	Cascapedia	375	...	...	300
	Black Capes	355	...	...	...
	Caplan	350	...	...	...
	Bonaventure	325	...	...	...
	New Carlisle	310	...	...	...
	Paspediac	300	...	...	...
	Marcil	280	...	...	230
	Port Daniel	275	...	...	240
	Newport	255	...	...	185
	Grand River	240	...	...	200
	Perce, northwest	225	225	...	...
	Corner of the Beach	225	...	...	...
	Barachois	225	...	...	...
	Divide	230	...	...	215
	Douglastown	235	...	...	...
	Gaspé	245	240	...	...

NEW BRUNSWICK

The positive determinations of the summit marine level in New Brunswick are relatively few, but they are widely distributed and some are of excellent quality.

The Saint John Valley is all too low for any record by the great river, and time did not permit exploration of the tributary valleys in the wilderness; for it should be understood that the great part of northern Quebec and New Brunswick and the interior of Gaspé and Nova Scotia are still in forest. The village of Grand Falls is on a gravel deposit in the midst of the valley, the summit, on the main street, being 520 feet altitude. Chalmers gives it as 522 feet. The full height of the summit water there is about 550 feet. The Grand River, joining the Saint John above Saint Leonard and Van Buren, carries high gravel plains up to the theoretic level, but the forest prevented precise measurement.

The features about Saint John City deserve particular description. Fortunately the Canadian Survey has recently mapped the quadrangle, and the writer is indebted to the Survey for an advance photolithograph and to Mr. A. O. Hayes, in charge of the topographic work, for directing attention to the critical locality.

Southwest of the city and south of South Bay is a heavy kame-moraine in which the Canadian Pacific Railway has a large gravel pit. The summit of this deposit has been swept by the sea, and along the Manawagonish road (old Saint Andrews road) for about four miles southwest of Fairville the cliffs and bars of the summit level are conspicuous. The middle section of this four-mile stretch is a ridge capped by wave-built gravel bars, which at two points rise to 200 feet. The western height is on land of Harold Chadwick and the eastern carries the home of A. H. Clark. The house of Mr. Clark is encircled by low bars of fine gravel, while a heavy bar extends northeastward. On the south face of the ridge just beneath the crest is a strong sea cliff with cobble and boulder terrace at elevation of 185 to 190 feet.

Due east of the city about three miles a careful examination was made of one locality, with discovery of a large and handsome gravel bar with altitude of 185 feet. No distinct wave-work could be found above the bar. This bar is on land of Michael Ryan and crosses the road just west of the second forks in the highway.

West by south of Saint John, 38 miles by rail (30 miles in direct line), is Pennfield Station, on the Saint Stephen branch of the Canadian Pacific Railway. This station is on a very extensive wave-swept gravel plain and has altitude 228 feet. For some four miles along the east and

MARINE COBBLE-PLAIN: PENNFIELD, NEW BRUNSWICK

At Pennfield Station, 30 miles southwest of Saint John, New Brunswick. Looking southeast. Altitude, 228 feet. Compare plate 16.

GRAVEL BAR ON THE PENNFIELD PLAIN

Thirty-two miles southwest of Saint John, New Brunswick, and one-fouth mile south of McKay Corners. Altitude, 225 feet. View looking west. Compare plate 15.

west road this plain is level, except for slight swells and hollows running across the road and declining seaward (plate 15). These are very evident to the eye, but have a relief of only one to three feet, except where deepened in a few places by recent drainage. The Pennfield Ridge post-office, one-half mile from the station, and McKay Corners, two miles west, have practically the same height as the station. On the road leading south from the school-house, near the post-office, is a remnant of a well stratified deposit of fine gravel and sand, with elevation 230 feet. One-fourth mile south of McKay Corners, on the road to Beaver Harbor, is a splendid bar of gravel lying across the road, with elevation 225 feet (plate 16).

Effective flow over the plain is shown by the abundant cobbles, up to six or eight inches diameter, with some subangular stones, built into piles over the fields or along the fences. We have here a plain swept by the tides, with a "washboard" surface declining seaward. The fluting is more apparent in the coarse detritus along the road and flattens out on the lower part of the plain composed of finer material. This fluted plain suggests the marine plain of the south side of Long Island, with its "creases," "furrows," or "dry rivers"; but the scale and relief here are smaller, probably related to the coarser material, steeper slope, and less width of the plain. Apparently this was the plain noted by Chalmers (6, page 10), with altitude 225 feet.

Other evidence of high-level waters is conspicuous in the region. The "Pocologan Barrens," northeast of Pennfield, stretch along the railroad for five miles—a waste of gravel and sand rising to at least 220 feet and carrying bars.

The great tidal range on this coast brings in a possible complication in the determination of the sealevel and the locating of the isobases. Today the tide at Saint John has a range of 27 feet. When the land stood some 200 feet lower and the Bay of Fundy was much enlarged, being really a strait connecting the Atlantic with the much enlarged Saint Lawrence Gulf, the tides here must have been much less, perhaps comparable to the present tides in the Saint Lawrence Gulf. A range of 15 feet is suggested. With this variation we may regard the summit bars on the Managonish ridge as highest tide-work and the 185-foot cliff as the principal horizon of wave action. This implies about 190 feet as the proper figure at the ridge. Taking into account the height and location of the bar east of the city and the Pennfield features, the 200-foot isobase is drawn through Saint John City.

The north and east portions of the province are not as closely determined for uplift, but the area lies between the precise stations of Saint John and Gaspé. A number of stations are given in the following tabu-

lation, with other theoretic altitudes, which may be guide for future study. Everywhere in the Maritime provinces beneath the theoretic plane the land shows standing-water features.

Altitudes of the earliest and highest Marine Levels

Location.		Theoretic altitude by isobases.	Observed altitudes.		
Stream valley and station.			Definite.	Approx.	Minimum.
Saint Croix River......	Saint Croix...........	395	...	400	...
	Pennfield Plain.......	225	225	...	...
Saint John Valley......	Saint John............	200	200	...	...
	Manawagonish Ridge.	195	190	...	...
	Ryan Bar, east of city	185	185	...	...
Keswick River.....	Upper Keswick.......	400	...	...	360
Nashwaak River...	Cross Creek..........	375	...	360	...
Upper Saint John River.	Grand Falls..........	550	...	...	520
Grand River.......	North of Saint Leonard	585	...	590 570	...
Grog Brook............	Millers	500	...	520 475	...
Canaan River..........	New Canaan.........	250	...	...	...
Salmon River..........	Little Forks..........	280	...	...	...
Petitcodiac River.......	Northeast of Moncton.	190	...	...	175
Richibucto River.......	Coal Branch.........	250	...	290 225	...
Barnaby River.........	Rogersville	300	...	305	...
S. W. Mirimichi River..	Boiestown	375	...	...	...
N. W. Mirimichi River..	Sevogle	345	...	...	...
Mirimichi River........	North of Newcastle...	315	...	310	...
Nipisiguit Valley.......	Red Pine............	330	...	340	...

NOVA SCOTIA

It appears that the south and east points of the peninsula and the east part of Cape Breton were not submerged, or, if so, the evidences are drowned. There is the lack of any of the ordinary phenomena produced by standing water; no stream deltas; no valley fillings; no wave-work on slopes and headlands. No record of submergence was found at Sydney, North Sydney, Sydney Mines, and Glace Bay, nor any along the coast from Liverpool around to Yarmouth.

Near the middle of Cape Breton, at Shenacadie station and southwest, along the secluded waters of Saint Andrews Channel, are weak but distinct bars and plains that have been raised a few feet above the reach of the present water. These shore features rise toward the southwest until

FIGURE 1.—SHORE AT LIVERPOOL, NOVA SCOTIA

Granite block on granite bedrock. Looking east at east edge of the village. Characteristic of the drift on the south shore of Nova Scotia.

FIGURE 2.—GRANITE BLOCK MORAINE: BARRINGTON PASSAGE, NOVA SCOTIA

At extreme south point of Nova Scotia. The common piling of granite block along the south shore.

GRANITE BLOCK MORAINES, NOVA SCOTIA

at New Glasgow they are 85 feet and somewhat higher at Truro. At the latter place and other stations on the Bay of Fundy and its branches the marine level is complicated by the probably large tidal range, even at the time of deep submergence. At Truro some weak evidence of water work was seen up to 100 feet, but excellent plains at 85 feet. The theoretical level is taken as 90 feet.

At Halifax the uplifted shore features are weak and rather uncertain, and on account of continuous fog they were not sufficiently examined; but the final adjustment of the isobases confirms the determination made on the ground, about 60 feet. Weak evidences at about the same height appear along Saint Margaret and Mahone bays.

From Liverpool around to Yarmouth the coast is strewn with huge granite blocks derived from the land on the northwest (plate 17). From Yarmouth to Digby the shore was not seen, the railroad lying across the interior, mostly in forest. At Digby and along the Annapolis Basin good delta plains and shorelines are conspicuous and were estimated in height up to 90 feet; but the maximum was not determined. According to the isobases, the altitude of the summit level here should be about 100 feet. The famous Annapolis Valley is filled with handsome gravel plains. The railroad, passing northeast, drops to 27 feet at Bridgeton and then rises steadily on the plains to 100 feet at Aylesford and to 138 feet at Berwick, the summit of grade. Probably some allowance must be made in this valley for the very high tides and storm waters forced across the col. The map makes the marine plane here about 125 feet, in agreement with the field conclusion.

About the Minas Basin the land is low. Up the Kennetcook River the delta and stream plains in the narrow valley are excellently displayed. The county of Cumberland, north of Cobequid highland, exhibits abundant submergence features, and the same is true of all the coast of Cumberland Strait and George Bay, counties of Pictou and Antigonish. In the district of Amherst and Springhill detrital plains are seen much above the theoretic marine level. These are attributed to the smoothing work of the extreme high tides which probably swept this area during the submergence.

In the valley of West River, between Antigonish and James River station, is a very heavy gravel kame area, and the aggraded plains rise from about 15 feet at Antigonish to 235 feet in the 9½ miles to James River, giving a gradient of 23 feet per mile.

East of Halifax the multitude of streams with flow direct to the Atlantic should hold excellent and positive summit deltas, but the coast is not easily accessible and is very wild away from the shore.

As the isobases record, negatively, the post-Glacial submergence, they should have some suggestive relation to the glacial load, and the disposition of the ice over Nova Scotia is important. The glacial features have been well described by Chalmers (8). He postulates several ice centers, or independent bodies on the higher tracts, with at least the later flow controlled by the large topography, and all toward the sea and larger bays. He attributed many inscriptions to icebergs, which may be true (8, pages 95-97). He seems to have minimized the ice-flow of the continental sheet southeastward across the Chignecto Isthmus (8, pages 93-95), for an area of drumlins in the Amherst region indicates a considerable current of ice from New Brunswick. This flowage probably deployed some distance over the peninsula; but Chalmers was probably correct in his view that the ice-sheet did not cross the Bay of Fundy, and that the flow in the southern peninsula was radial from the interior.

Chalmers found no evidence of glaciation on the Magdalen Islands nor on the northern part of Prince Edward Island. He says, page 91:

"The Magdalen Islands are non-glaciated, and it would seem that the mainland ice has gone no farther than the eastern and northeastern border of Prince Edward Island, the southeastern part having, apparently, been glaciated by the ice which accumulated on the island itself."

Chalmers gives in this report a tabulation of the marine beaches (pages 21-25), and while his figures are not always consistent among themselves and are partly of inferior features, they are in general decidedly confirmatory of the isobases as drawn for Nova Scotia, and some are in close or precise agreement. The 100-foot isobase has been laid in accordance with Chalmers' levels for the Magdalen Islands, 110 to 115 feet. But the map does not agree with his figures for Prince Edward Island, which are all 75 feet except one station for 80 and one for 95 feet. Perhaps his 75-foot shore correlates with the strong beach in the Gaspé district at 85 feet and represents a relative pause in the later uplift. Tyrrell's Newfoundland terrace at 100 feet may represent the same pause (see later reference to this).

The local glaciation of the Nova Scotia region helps to explain the lack of deep submergence. The piling of immense quantities of hugh granite blocks along the coastal area, at least from Liverpool to Barrington Passage (Cape Sable), might, at first thought, suggest that the ice-body was sufficient to depress the land to an extent inconsistent with the evidence; but the drift is piled in practically block moraine along the land border (plate 17). The ice did not have sufficient depth and push to sweep the drift into the sea. As stated above, only a tongue of the Labra-

dor ice-sheet reached the peninsula, and the local ice-bodies were probably thin and short-lived. On the other hand, Newfoundland, larger in area and farther north, held a massive glacier with effective weight.

Examination should be made of the Cape Canso district and the east part of Cape Breton. The Nova Scotian region is a critical area for checking the relation of the glacier to the diastrophic movements.

Altitudes of the earliest and highest Marine Levels

Location.		Theoretic altitude by isobases.	Observed altitudes.		
Stream valley and station.			Definite.	Approx.	Minimum.
Ocean shore	Yarmouth to Liverpool	0	0	...	...
Lahave River	Bridgewater	25	...	20	...
Mahone Bay	Chester	50	...	75 50	...
Saint Margaret Bay	Hubbard	55	...	53	45
Halifax Harbor	Halifax	50	...	60 50	...
Annapolis Valley	Digby	105	...	...	90
	Annapolis	115	...	...	...
	Lawrencetown	120	...	...	...
	Aylesford	125	...	...	110
	Berwick	125	138 125	125	...
Gaspereau River	Gaspereau	120	...	...	...
Saint Croix River	Newport	110	...	...	...
Kennetcook River	Kennetcook	100	...	100	95
Salmon River	Truro	90	100 85	... 90	... 85
Philip River	Oxford Junction	150	160 125	...	...
Maccan River	Springfield Junction	165	...	200 125	150
East River	New Glasgow	80	85	...	...
West River	Antigonish	50	...	...	30
South River	South River	45	...	...	22
About George Bay	Pomquet	40	...	...	30
	Tracadie	30	...	...	25
	Monastery	25	23	...	...
Denys River, Cape Breton.	River Denys	10	...	10	...
On Bras D'or Lake	Orangedale	15	...	...	12
	McKinnon Harbor	10	...	...	7
Saint Andrews Channel	Shenacadie	5	3	...	...

A few selected stations from Chalmers' tabulation of ancient marine levels (8, M, pages 22-25) are given below in comparison with the theoretic altitude by the isobases of the map:

Chalmers' number.	Station.	Chalmers' elevation.	Isobasal value.
	NOVA SCOTIA		
20	Half a mile north of Nappan station, I. C. R.......	143.72	175
23	Between Wallace Harbor and Pugwash...........	133	140
24	On peninsula north of Wallace Harbor, in several places, distinct...............................	133	140
25	East of Wallace, on road running south from Plaster Cove.................................	138	135
26	On Wallace Ridge, east of road going south from Plaster Cove, in several places.................	133	135
30	At Thomson station, I. C. R......................	138	140
31	On east side of Halfway River, at northern base of Cobequid Mountains..........................	170.84	155
31	At mouth of L. Quille Brook, south of Annapolis..	110–115	110
42	Near head of Saint Marys Bay, at base of North Mountain....................................	110	110
	MAGDALEN ISLANDS		
53	On Amherst, Entry, Grindstone and Alright Islands	110–115	110

LABRADOR AND NEWFOUNDLAND

Fortunately we have for mapping of the uplift of the Labrador coast a consistent set of carefully determined elevations of summit beaches by Professor Daly (39), including three well distributed altitudes in Newfoundland. These figures are the basis for the isobases of those provinces. The isobases of 300 and 400 feet along the Labrador coast appear to harmonize all of Daly's beach levels, and his figures are supplemented by at least one observation by Professor Coleman. In a letter relating to exploration in the summer of 1916 Coleman says:

> "The highest levels along the northern part of the coast where I was working are below those of the Saint Lawrence region. Four hundred and thirty feet was the highest certain beach, in about latitude 56° 30′. From this northward there is a lowering to 225 feet at Komaktorvik Bay, about latitude 59° 30′, my most northerly point.
>
> "The beaches in Newfoundland seem higher than in the part of Labrador I have studied, reaching 500 feet or more."

Coleman's higher elevation does not harmonize with the map, but his lower figure, 225 feet, lying north of Daly's farthest and lowest station at 250 feet, is in perfect accord.

A. P. Low has given (20, page 310) an elevation of 180 feet for the high beach at Nachvack Bay. Evidently Low did not find the summit level, and the figures of A. S. Packard, 200 feet for the highest beach of the coast, are also beneath the summit (24, page 310). But Low's beach elevations for the coast of Hudson Strait (22, page 47 L), 405 feet, are in good accordance and are used for the 400-foot isobase of that coast.

Of these beaches he said:

"The terraces at Dyke Head lie in a small valley at the bottom of a cove facing the strait, and afforded one of the best examples of terraced beaches seen on the coast, the heights being 405, 330, 275, 255, 220, 175, 90, and 85 feet."

His figures for Ungava Bay, 300 to 325 feet, must be of inferior water levels.

For the Hudson Bay coast the only available figures are those of Low. His description of the successive levels in the district of Richmond Gulf (21, page 41 L) seem accurate and discriminating, and his reiterated statement (22, page 46 L; 23, page 81 D) that the marine summit is 700 feet or over is relied on for the position of the isobase of that value.

In his papers on the wide region west of Hudson Bay, J. B. Tyrrell has noted high-level beaches which he discriminates from those of Lake Agassiz and of other glacial waters (30, 33). He found beaches which he regarded as marine up to 490 feet near Doobawnt Lake, northwest of Hudson Bay; and up to 600 feet south of Nelson River, between Lake Winnepeg and Hudson Bay (30, pages 190-193 F). It appears probable that the ice displaced the shallow waters of Hudson Bay, and that the isobases should lie across the bay, but the present information is too meager to justify the westward projection over that area.

For Newfoundland it seems necessary to recognize an independent area of glaciation and uplift amounting to at least 600 feet. The observations of Daly and others are for the coast, but the interior of the island, where the ice-burden was greater, must have suffered more movement. In a personal communication Professor Daly expresses confidence in the practical accuracy of his figures for Cape Rouge Harbor, 505 feet, and Kirpon Island, 450 feet plus; but he hopes that the level at Saint John, which he estimated at about 575 feet, may be more leisurely and precisely measured (39, pages 257-259).

Besides the figures by Daly on the northeast coast, we have some suggestive ones by Tyrrell on the west coast. Writing of a visit to Newfoundland during the summer of 1917, he says:

"In Newfoundland the last glaciation, which was very strong, was from the center outward both eastward and westward. If the glacier from Labrador

had ever reached the island, evidence of its presence should have been discernible on the west coast, but in the short time I was there I was not able to find any such evidence.

"The presence of post-Glacial terraces is quite strong along the west side of the island from Bay Saint George up to Bonne Bay, especially as looked at from a boat half a mile or so off the shore. One terrace is about 30 or 40 feet above sealevel. Above this is a rather extensive plain about 100 feet above sealevel, composed on the surface of sand and gravel. The old beach on the border of this plain might be 15 or 20 feet higher. . . . Other terraces extend 200 or 300 feet higher, and while in some places, at an elevation of, say, perhaps 300 feet, I saw clear evidence of the work of the tide in cutting little runnels on a steep limestone slope, I was not able to measure the exact height of this beach."

The stations and altitudes which have been used in placing the isobases of Labrador and Newfoundland are listed below:

LABRADOR

From Daly, going north from Belle Isle Strait:

Saint Francis Harbor	365
Ice Tickle	265
Northwest of Conical Island, mainland	290+
Pomiadluk Point	345
Aillik Bay	355
Hopedale	390
Quirk Tickle	340
Ford Harbor	290
Black Island Harbor (Newark Island)	290
Port Manvers	285
Cutthroat Tickle, 25 miles north	270
Mugford Tickle	265
Hebron	260
Kipsimarvik, Nachvak Bay	250

From Coleman:

Latitude 59° 30′	225

From Low:

Hudson Strait, Douglas Harbor, southwest arm	405
Hudson Strait, near Dyke Head, over 100 miles east	405
Hudson Bay, vicinity of Richmond Gulf	700+

NEWFOUNDLAND

From Daly:

Saint John (estimated)	575
Cape Rouge Harbor	505
Kirpon Island	450+

From Coleman:

Locality not given	500±

From Tyrrell:

Port au Port, East Bay	300–400
Bonne Bay, North Point	300–400

All available information on the glacial geology of Newfoundland favors an independent ice-cap, with radial flow.[4] And when we consider the large area and mountain heights of the island; the northern position; exposure to ocean on all sides; and location in the paths of the cyclonic storms of America, it appears certain that the island was the locus of heavy snow precipitation and a massive ice-cap—the Newfoundland continental glacier.

The opinion of some Canadian geologists assigning local ice centers to Gaspé, the highlands south of the Saint Lawrence, Nova Scotia, and Newfoundland is quite certainly true for Newfoundland, probably true for Nova Scotia, and possibly true for other highland districts, at least for the waning stage of glaciation.

The ice-sheets deployed widely on the land, but seem to have been inhibited by the sea, especially where the tides were strong and heavy storms were frequent.

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Lists of writings which have some bearing on the problems of post-Glacial continental uplift, particularly on the area of New York and the adjacent territory, have been published in the papers numbered 81-84 in the following list. Only a very few titles from the former lists are repeated here. The present list is mostly of papers relating to Canada and New England.

Bibliographies by other authors on glacial geology have been published as follows:

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On the Pleistocene of New England northeast of Boston, to 1908, by Clapp, in number 74, by references.

A very full and well annotated list of the glacial literature, relating especially to the region of the Great Lakes, to 1915, is given in Leverett and Taylor's monograph, number 80.

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EXPLANATION OF THE ABANDONED BEACHES ABOUT THE SOUTH END OF LAKE MICHIGAN [1]

BY G. FREDERICK WRIGHT

(Presented in abstract before the Society December 28, 1916)

CONTENTS

Description of the Beaches

Three abandoned postglacial beaches at the south end of Lake Michigan have been known for many years. In 1870 Dr. Edmund Andrews described them in a very elaborate paper published by the Chicago Academy of Sciences. Later, Mr. Leverett, in his monograph, "Illinois glacial lobe," and Mr. William C. Alden, in his Chicago Folio of the U. S. Geological Survey, have collected the facts in very full measure. From these and other published observations it appears that, surrounding the south end of Lake Michigan from about the vicinity of Waukegan, on the west side, and extending indefinitely northward on the east side, there is an abandoned beach approximately 60 feet above the level of the lake. This is called the Glenwood beach.

Twenty feet lower, or about 40 feet above the present level of the lake, occurs what is called the Calumet beach. Twenty feet lower still, or approximately 20 feet above the level of the lake, occurs the Tolleston beach. These are shown on the accompanying map (figure 1), compiled

[1] Manuscript received by the Secretary of the Society March 19, 1918.

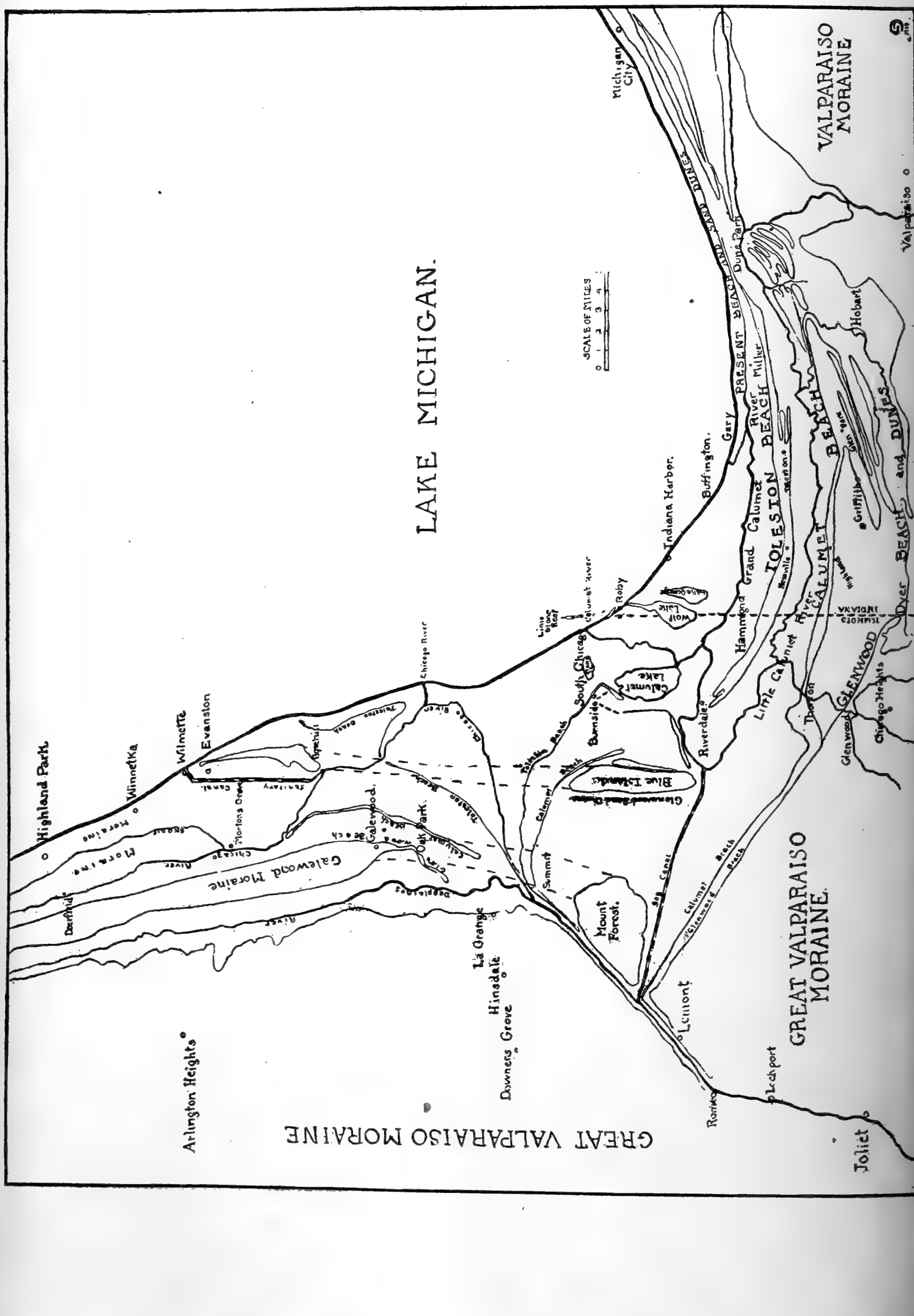

FIGURE 1.—*Postglacial Beaches around the southern End of Lake Michigan*

Compiled and drawn by Miss Lonie Shedd. The broken lines south of Galewood and Rosehill moraines indicate the probable extension of those moraines supposed to have been washed down by the waves of Lake Chicago. For a description of the beaches, see text.

from the Chicago Folio of the region south of the lake. All these beaches are interrupted by the Chicago outlet along the line of the present drainage canal, this outlet having served its purpose during the formation of them all.

Peat Deposits between the Second and Third Beaches

The facts most difficult of explanation connected with these beaches are the accumulations of beds of peaty material underlying the second (Calumet) beach. These were noticed by Doctor Andrews at various places, especially near Evanston, where they not only underlie the second beach, but

"extend eastward across the interval between it and the third beach. Its level is no higher than that of the third beach, being only 12 to 15 feet above the present level of Lake Michigan. . . . The peat is immediately overlaid by about five feet of sand, above which there is a bed of coarse gravel. The gravel is thin near the borders of the bar, but has a thickness of 10 or 12 feet at the highest part. It is capped by a thin deposit of sand, and has also layers of sand interbedded in its thickest parts. The presence of this gravel makes it certain that the old marshy land surface has not been buried by the drifting of material from the lower beach. There seems no escape from the conclusion that the lake stood at a lower stage than the level of the second beach before that beach and the bar under discussion were formed." [2]

Also, according to Leverett: [3]

"For a few miles in the vicinity of the State line between Indiana and Michigan there are exposures of peaty material along the bluff of Lake Michigan at levels ranging from about 15 feet above the lake down to the water's edge. . . . Near Michigan City peaty layers just above the water's edge are nearly continuous for a distance of a mile or more and occur at frequent intervals from Michigan City to the Michigan State line. Above the peaty beds pebbly sand in places reaches an elevation of 30 feet above the lake, or nearly to the level of the second beach. The peat appears, therefore, to have been developed prior to the formation of that beach, and probably has the same age as that noted near Evanston, Illinois."

Later, however, in Monograph LIII, Mr. Leverett hesitates about accepting this evidence as conclusive. Speaking of the Evanston peat deposits, he suggests that

"a bar might be extended out over a peat deposit standing at the same level as the lake and press it down and thus give it a lower level than it had while in process of growth. At the Evanston locality this interpretation would seem very plausible, for the bar was built out into water of considerable depth by southward-moving currents." [4]

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[2] Leverett: Illinois glacial lobe, p. 445.
[3] Ibid., p. 445.
[4] Ibid., p. 356.

It is difficult to see the force of this suggestion of Mr. Leverett. How could a thickness of 10 or 12 feet of gravel, capped by a thin deposit of sand, be pushed out into water of considerable depth to cover a deposit of peat that was originally at the level of the southward moving currents which deposited the bar? The conception is impossible. We shall be justified, therefore, in accepting the original conclusions of Doctor Andrews and Mr. Leverett, which were formed when these Evanston deposits were all exposed. Unfortunately, at the present time the growth of the city has so modified the shore that the facts are not now open to inspection.

Speaking further of the peat deposits near Michigan City, he says:

"The sand evidently was deposited during the development of that beach and the peat is certainly as old as the beach. The beach may have been extended out over a peaty deposit, as was suggested in the case of the Evanston deposits, but the conditions on the whole do not strongly favor this view." [5]

To establish the early date of the peat, Mr. Leverett would demand the discovery of valleys which entered the lake at this lower stage, at a level below the Calumet beach, and which had been built across by the Calumet beach; but in the lack of such evidence it is not necessary to give it much weight.

The Series of Moraines

As will be seen from the map, the outlet has two branches coming together at the Sag. These are separated by Mount Forest Island, which is in the main a moraine deposit. From the Sag westward through Lemont to Lockport the channel is on a dead level, running over a rock shelf 8 feet above Lake Michigan. At Lockport it descends through Joliet and some distance below, 35 or 40 feet in a few miles. At the foot of this descent there are immense gravel deposits (including many boulders a foot or more in diameter) on the west side of the Des Plaines River, rising 60 feet above the river plane and covering fully a square mile. The gravel is also 40 feet in depth below the river plane.

Properly to interpret the history of this outlet, we must consider the series of moraines on the west side of the lake. The outer moraine is many miles in width, extending all around the south end. It is called by Leverett the Valparaiso moraine. North of the outlet there are two or three narrow parallel moraines extending from the north, but at present not reaching the south end of the lake. Numbering from the west, the Galewood moraine is separated from the Valparaiso moraine by a valley 2 or 3 miles wide, through which the Des Plaines River flows. A little

[5] Ibid., p. 256.

farther east the Rose Hill moraine is found, but does not at present project quite so far south. The space between this and the Galewood moraine is occupied by the Chicago River. Going farther north, there are remnants of a parallel moraine above Evanston. These all seem to be lateral moraines formed when the ice in shrunken quantities extended toward the south end of the lake, but the erosion of the water has very likely removed their extreme southern ends, so that their existence can only be inferred; but Mr. Leverett thinks it not at all improbable that the Rose Hill moraine extended southward to Blue Island, which is certainly a moraine formation 6 miles long, since the rock does not appear underneath it until a depth of 50 or 60 feet is reached, while it rises more than 60 feet above the lake level.

It would seem also likely that the Galewood moraine extended to Mount Forest Island, which is deeply covered with moraine material. As a partial proof of this, it is to be noted that the 60-foot terrace extends southward from Galewood through Oak Park well on toward Mount Forest Island.

History of the Chicago Outlet

It is true that this 60-foot beach through Oak Park, like the 40-foot beach which extends toward Blue Island, is composed of stratified sand and gravel; but as the erosive agencies of the lake when at its higher levels probably operated for several thousand years, and as these agencies are known at the present time to be eating into the bank at rates varying from 2 to 3 feet a year, there was ample opportunity for them to level these narrow moraines and so in part to account for the material forming the present Glenwood and Calumet beaches in that vicinity.

But this is preliminary to considerations bearing on the opening of the outlet followed by the Drainage Canal and the Des Plaines River. This channel, as well as both the Sag and Des Plaines outlets which join to form it, is from 1 to 2 miles wide, with rocky sides rising at La Grange, on the north, 60 feet above the lake, and at Lemont, on the south side, to the same height. Farther in the interior moraine deposits rise to a height of 160 feet above the lake. The level of the rock bed of the outlet, as already said, is 8 feet above the lake.

Two suppositions have been resorted to in accounting for the accumulation of peat underneath the Calumet beach. Mr. Alden suggested that the water fell to the level of the Tolleston beach by being drained off eastward as the ice had receded and opened up channels in that direction, and that this continued for sufficient time for the peat to accumulate, when a readvance of the ice closed up those outlets and raised the water

to a 40-foot level. Others resort to the supposition that there was an elevation of the land north of the outlet sufficient to allow the accumulation of peat, and that afterward there was a depression to the Calumet level.

The only direct evidence supposed to indicate such a temporary land elevation is drawn from soundings in various narrow lakes tributary to Lake Michigan on the east side, which in several cases descend at least 50 feet below the present level of the lake. But it would seem altogether probable that these are preglacial channels or depressions preserved, by the presence of ice, from being filled with glacial material.

Supposed Changes of Land Levels

A recent survey of the whole region, under the guidance of Mr. Charles B. Shedd, suggests a theory which avoids the obvious difficulties connected with the other theories and is supported by all the facts and causes known to be in operation.

The 60-foot water level, during which the first beach was formed, is accounted for by the natural supposition that the drainage outlet from Summit to Joliet was filled with glacial deposits, compelling the water to rise to that level. Naturally the clearing out of this channel would take place by a process that is called "stoping"—that is, by a wearing back from the Joliet end by a recession somewhat similar to that which takes place in waterfalls. Otherwise there would have been a succession of numerous small beaches. Their absence shows that the water was kept up to the 60-foot level until the removal of the obstruction through its whole extent, constituting the Glenwood period.

Very interesting Glenwood dunes are to be seen on the west side of Blue Island, already referred to as a narrow mass of morainic character, some 5 or 6 miles in length, that stood above the 60-foot level of the lake. These were evidently formed out of the shallow water deposit to the west during the Glenwood stage, as is shown by their long slope to the west and their abrupt slope to the east; they are of finer material, more oxidized than most of the other dunes, and now covered with grass and large trees.

Supposed earlier Opening of the Sag Outlet

Mr. Shedd has suggested that naturally the Sag outlet was opened before the Des Plaines River outlet to the north of Mount Forest Island, which he thinks was probably closed during the Glenwood stage by the prolongation of the moraine from Galewood down to Mount Forest Island, probably maintaining the Sag outlet to the 60-foot level during

the Glenwood stage, and that while the Des Plaines River from the north was digging and deepening its channel on the west side of the moraine and to the Sag and beyond, that the east side of the moraine was being washed down and spread out by wave action, as was the case all along the west shore of Lake Michigan, for nearly a mile in width, until it was washed down, and the 60-foot waters of Lake Chicago suddenly rushed through into the deepened Des Plaines Channel, lowering the water level to the 20-foot Tolleston stage, when little or no water passed through the narrow Sag Channel, afterward widened out by the long-continued deeper flow of the Calumet stage.

This is a plausible theory if it can be substantiated and proved by further examination. In any event it seems quite evident that the water was in some way lowered down quickly to the 20-foot Tolleston stage and maintained there long enough for the formation of the peat beds that have been referred to.

Effects of the Diversion of the Water in the glacial Lakes in the Erie-Ontario Basin

A natural explanation of the long-continued 40-foot water level producing the second, or Calumet, terrace is found in the immense accession of water to the south end of Lake Michigan from the glacial lake which had been ponded in the Erie-Huron-Ontario Basin, which covered many thousand square miles and was at first approximately 200 feet above the present level of Lake Michigan. This body of water having its outlet at first into the Ohio Basin through a well defined channel at Fort Wayne, Indiana, was lowered at successive stages as the ice receded northward. First, there was a fall of approximately 50 feet when the Imlay outlet across the thumb in Michigan was opened into the Grand River Valley, and another 50 feet when the Ubly outlet farther north was opened by the retreating ice, and, according to Mr. Taylor's estimates, another 20-foot fall when the ice had receded beyond the thumb, letting the waters of Lake Warren through Saginaw Bay into the Grand River Valley. These three stages of water, named successively Lake Maumee, Lake Whittlesey, and Lake Warren, are clearly marked by abandoned shorelines on the south side of Lake Erie. A beach 200 feet above Lake Erie leads around to Fort Wayne, where it is interrupted by the channel of the original outlet and resumed again on the other side. The 150-foot beach leads around to the Imlay outlet and the 100-foot beach around to the Ubly and Saginaw outlets.

This would still leave an enlarging basin of water, covering many thousand square miles, 70 feet above the Chicago outlet, continuing until

the ice had receded beyond Mackinac, when it would pour through the straits to Lake Michigan, though there may be some doubt as to when the outlet through the Mohawk Valley to the east was so opened as to take off a part of this lower accumulation. The opening through the Mohawk Basin and Niagara gorge at last would bring the water down to its present level.

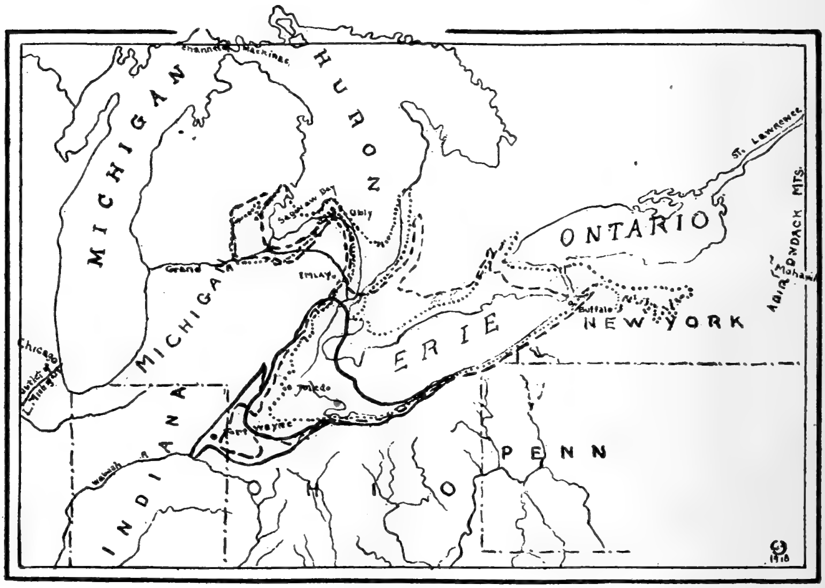

FIGURE 2.—*Stages of glacial Lakes in the Erie-Ontario Basin*

------ Boundary of lakes Maumee and Whittlesey and the Imlay outlet into Lake Michigan

...... Boundary of Lake Warren, with its Ubly and Saginaw outlets into Lake Michigan

Compiled and drawn by Miss Lonie Shedd. Fort Wayne, outlet into the Wabash River of Lake Maumee, about 200 feet above Lake Erie, as glacier ice-front receded. Imlay, outlet of Lake Maumee through Grand River down to level of Lake Whittlesey, about 150 feet above Lake Erie. Ubly, outlet of Lake Whittlesey through Grand River down to level of Lake Warren, about 100 feet above Lake Erie. Saginaw Bay, outlet of Lake Warren through Grand River to about 70 feet above Lake Erie.

That this influx of water from the Lake Erie Basin would be sufficient to raise Lake Chicago to a 40-foot level is easily believed when we consider the size and depth of the outlet at Fort Wayne and the extent of the glacial lakes which occupied the Erie-Ontario Basin. The old outlet, now occupied by the major portion of the city of Fort Wayne, is nearly 2 miles wide and 20 feet in depth, such a channel having been necessary to carry off the surplus water from the melting ice to the northward. When the opening into Lake Chicago through the Grand River valley occurred, all this surplus water, as well as that ponded up to the 200-

foot level in the Lake Erie Basin, would have to find its way through the Chicago outlet. No one who examines the facts can hesitate to believe in the sufficiency of this water supply to produce the known results. It is fair to say that this explanation is suggested in a single sentence by Mr. F. B. Taylor on page 326 of Monograph LIII, where he says: "The changes which occurred in Lake Chicago were due to erosion of its outlet or to changes in the volume of its discharge."

Glacial and Clay Deposits underneath Chicago

Mr. Shedd calls attention to a deposit of soft putty-like blue clay that overlies the hard-pan glacial drift underneath all the Chicago region, wherever caissons have been sunk or channels dug. From information furnished by Mr. George W. Jackson, who has built 110 miles of tunnel under the city of Chicago, and from Mr. John Griffiths and other engineers who have sunk innumerable caissons to the solid rock for the support of the great buildings of the city, we learn that below a few feet of muck and yellow loam, which form the surface deposit over this area, there is regularly from 20 to 40 feet of soft blue clay resting on the till, which extends in most cases about 60 feet farther down to the solid rock, which in many cases shows grooves and stretches characteristic of glacial surfaces. Mr. Griffiths gave me a piece of Lake Superior copper which he had found a few days before, 60 feet below the surface, in a caisson which he was sinking at the corner of Harrison and Canal streets.

FIGURE 3.—*Section of laminated Clay above the soft blue Clay appearing in the diversion Channel at Evanston.*

Mr. Jackson reports that beneath the till over the hard limestone rock there frequently occurs a stratum 3 or 4 inches thick of "black torpedo gravel from the size of a pinhead to a pea." This succession of deposits continues substantially the same 2 or 3 miles out into the lake east of Jackson Park, where he put in the Hyde Park water works tunnel and crib. Mr. Shedd also reports a similar succession at Wolf Lake, in the

southern extremity of Chicago, and at Evanston, north of the city, where the new diversion channel is in process of construction. A photograph of a section of the deposit is here shown (see figure 3). The significance of this with reference to the raised beaches under consideration is easily seen. The few feet of clay muck and yellow loam covering the surface is evidently a deposit connected with the Tolleston beach or the Calumet beach, both deposited after the Glenwood stage. The thick deposit of soft blue clay underlying it must have taken place in the deep water which prevailed during the formation of the Glenwood beach. More careful and extensive study of these deposits is required to determine the length of time required for their deposition. As near as we could estimate, there are 100 of these clay laminæ to the foot in the upper deposit.

Provisional Estimates of Glacial Time afforded in this Area

Assuming that each of the laminæ represents an annual deposit, which, however, is by no means certain, that would give 4,000 years for the continuance of the Glenwood stage of water. This calculation is roughly approximate to that made from deposits in the bottom of Lake Maumee, in the Lake Erie basin, where 35 feet of fine sediment had accumulated in laminæ which numbered 8 to the inch. These calculations, also, roughly approximate those made by Doctor Andrews concerning the time required for the accumulation of the dunes at the south end of Lake Michigan, which he estimates to be 6,000 years, though later authorities have, however, questioned the correctness of some of his data.

All this, however, precedes the time during which Lake Michigan has occupied its present level, determined by the eastward drainage of its waters. The most promising method of estimating this time is presented in the estimated amount and rate of the erosion of its western banks by the waters of the lake. The extent of this erosion is revealed by the width of the shallow shelf covered by about 60 feet of water, which extends out to the deeper depths of the lake. Assuming that the margin of these 60-foot soundings follow the old shoreline, which is now at an average distance of 2.72 miles from the present shore, and that the rate of erosion (3.33 feet) determined by the Wisconsin Survey is correct, the age of the present lake would be only 4,708 years. Granting that these estimates are at the best only a rude approximation, Mr. Leverett concedes that they "have much value in their bearing on the length of postglacial time," and quotes with approval Doctor Andrews's remark

> "that they are useful in showing that it is impossible to allow, even on the most liberal estimates, any such postglacial antiquity as 100,000 years, which has often been claimed." [6]

[6] Illinois glacial lobe, p. 459.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

AGE OF THE AMERICAN MORRISON AND EAST AFRICAN TENDAGURU FORMATIONS [1]

BY CHARLES SCHUCHERT

(Read before the Paleontological Society December 28, 1916)

CONTENTS

[1] Manuscript received by the Secretary of the Society September 28, 1917.

Summary

This study was begun with the idea that the conclusion would be the certain transferal of the Morrison to the Lower Cretaceous or Comanchian. The writer, from a preliminary study made two years ago of some of the results of the findings in East Africa, was led to this belief, but as the final study progressed it became plain that if the Morrison could be shown to be of Comanchian time at all it would have to be referred to the earliest part of this period. To make certain of the facts, the writer took up correspondence with several of his friends, resulting in the conclusion that for the present the Morrison is best left in the Jurassic, where it has been placed by most American paleontologists.

The marine Sundance beneath the Morrison has several forms of ammonites, one of which is *Cardioceras cordiforme,* a species of great stratigraphic significance. If it is a genuine *Cardioceras,* its age is early Upper Jurassic (Corallian = Argovian), and if a *Quenstedtoceras,* then latest Middle Jurassic (Oxfordian = Divesian). On the other hand, it appears to be definitely excluded from *Amœboceras,* and hence from the Kimmeridgian series. Accordingly, the Sundance is either of latest Middle Jurassic or earliest Upper Jurassic. There is, therefore, in the Great Plains country a long time interval before marine strata are again met with in the Purgatoire formation, one of the members of the Washita series of the Comanchian. In this interval was deposited the Morrison formation of fresh-water origin.

Until a few years ago it was widely held that the Morrison lies with unbroken sequence on the Sundance, and since the latter is of either late Middle or earliest Upper Jurassic time, it followed, since they were in continuous deposition, that the former must also belong to this period. Now most stratigraphers are agreed that the two formations are not bound together by transition beds, and, further, that the Morrison is a transgressive series of fresh-water strata over the marine Sundance. In many places the two formations do not follow one another and the Morrison has a strikingly different geographic distribution from the Sundance. The latter extends, ever widening in area, to the north and northwest into the Pacific, while the Morrison distribution is greatest in the opposite direction, widening to the south. Pardee has recently shown that there is no Morrison in the Garrison and Phillipsburg quadrangles of Montana, and that the Kootenai here rests directly on the Sundance. Therefore in correlating the Morrison we have no means of determining the length of time represented by the break or disconformity between it and the Sundance, and until recently the organic content of the former

was not checked into the marine sequence. Even now all that we can safely state is that it appears more probable that the Morrison is of Upper Jurassic age than of early Lower Cretaceous time.

What caused the withdrawal of the Sundance or Logan sea is not yet known, but it may have resulted from the elevation of the Sierra Nevada Mountains, a diastrophic movement of great magnitude. In any event, after Sundance time the Pacific Ocean never again spread east of the western Cordilleras. Not only this, but the marginal overlaps of this ocean were smaller in area after Jurassic time than they had been before this period. For a time the writer sought to connect the deposition of the Morrison with the Sierra Nevada crustal movement and thought that it followed the culmination of this diastrophism. Lee, however, emphasizes the close paleophysiographic similarities of the environments of the Sundance, Morrison, and Purgatoire formations, indicating that the Sierra Nevada movement did not affect the area of these deposits lying far to the eastward.

From the synopsis presented beyond of the very interesting work of German paleontologists, it is seen that in the Tendaguru of East Africa there are two marine zones replete with guide fossils, and that beneath each one there is a dinosaur horizon having sauropods very similar to those in the Morrison. The whole series is regarded as one of continuous deposition and is replete with interest, not only because of the varied fossils of the sea and land, but further in that we get here a better understanding than heretofore as to the habitats of the sauropod dinosaurs. The upper marine *Trigonia schwarzi* zone is clearly of Lower Cretaceous or Neocomian time, while the middle *T. smeei* zone is of late Jurassic or more definitely of early Upper Kimmeridgian time. Accordingly the German stratigraphers refer the upper dinosaur horizon to the Lower Cretaceous and correlate it with the Wealden of Neocomian age, while the middle dinosaur horizon is regarded as of the older Kimmeridgian. The dinosaurs, and more especially the sauropods, are held, as a result of the preliminary studies, to be very much alike in both horizons, though later on it may be seen that they are somewhat different in each level. In any event, they are very much like those of the Morrison and thus help to fix the time of the American formation.

As the ammonites of the *Trigonia smeei* zone are of the older Kimmeridgian and as in the standard sections of western Europe there is still considerable Jurassic time left, it would appear more natural to regard the upper dinosaur zone as filling this time, because of the continuous deposition of the Tendaguru series. This is not the view of the Germans, and the one here presented was first suggested to the writer by

Dr. S. S. Buckman, of England. It appears, however, to be the obvious correlation to make and if done seems to explain better the close similarity of the saurians in the two upper dinosaur zones. Further, as the East African dinosaurs are so very much like those of the Morrison, and as this is especially true of the sauropods, the evidence appears to indicate that all of these animals are of Upper Jurassic age. Accordingly the Morrison may be of this time; but as these saurians are also related to the very fragmentary ones of the Wealden, which are of early Comanchian time, it seems best at present not to be too quick in accepting the view that the Morrison is Jurassic.

The Morrison and Sundance Formations

NAMES APPLIED TO THE MORRISON

The Morrison formation of the Great Plains is widely known as the one which has furnished since 1877 the most striking of all fossil animals, the great dinosaurs. They were first successfully collected near Morrison and in Garden Park, near Canyon City, Colorado; later at Como Bluff and elsewhere in Wyoming, and most recently in Utah. At first these deposits were known as the Atlantosaurus beds, a name given them by Marsh; later they were called the Como beds by Scott, the Gunnison formation by Eldridge, and the McElmo and the Morrison formation by Cross; the last term, proposed in 1894, is now in general use.

CHARACTERISTICS AND DISTRIBUTION

The Morrison of eastern Colorado and central Wyoming, Stanton writes, [2]

"consists of variegated marls and shales with irregular beds of sandstone and sometimes thinner layers and lenses of siliceous limestone. The colors of the shales and marls are greenish gray, purplish, maroon and red, very irregularly distributed, while the sandstones are usually gray, sometimes weathering brown or with small brown spots."

The sandstones often channel into the clays and then occur as lenses, and it is very probable that most of the red color of the shales is due to secondary causes or weathering.

"The limestones are gray, in some cases weathering with a reddish tinge. The general appearance of the formation is remarkably uniform over large areas, and yet the individual elements are so variable that no two detailed sections are exact duplicates of each other."

[2] T. W. Stanton: The Morrison formation and its relation with the Comanche series and the Dakota formation. Jour. Geology, vol. 13, 1905, pp. 657-658.

Or, as Lee says, the strata are "uniformly variable." Mook states that the coarsest material and the thickest beds of quartz sands and arkoses occur in the western areas and in most places in the basal beds, though arkosic sandstones are sometimes present in the middle zone. The fine sediments, mainly of clays, are found throughout and comprise the largest and most typical element in the formation.

The Morrison, according to Lee,[3]

"extends from Montana to New Mexico and from the Black Hills and eastern New Mexico westward to Utah. . . . It was probably deposited over flood-plains on a nearly flat surface [as first held by Hatcher], in lagoons and temporary lakes, and in marshes along sluggish streams."

Mook[4] concludes that the original area of distribution of the Morrison

"probably amounted to four or five hundred thousand square miles and perhaps more." "The Morrison is essentially a broad alluvial plain, formed of coalescing alluvial fans, and possibly a true delta in the southeastern areas." "The thickness is much greater in the western areas than in the eastern and there is a thinning out eastward, which is very gradual considering the distances involved."

The same writer states that in the extreme west of Colorado and in Utah the thickness varies from 400 to over 1,000 feet; in the Owl Creek and Bighorn Mountains of Wyoming it is usually between 200 and 150 feet; near Great Falls, Montana, about 100 feet; in central Colorado between 350 and 450 feet; in eastern Wyoming and Colorado about 200 feet; in east-central New Mexico between 200 and 400 feet; and in the Black Hills of South Dakota less than 100 feet.

Lee's ideas of the physiographic environment of the Morrison are borne out by Lull's conclusions[5] that

"the habitat of the Sauropoda may best be visualized by imagining conditions such as now exist in tropical America, more especially over the coastal plain of the lower Amazon: low-lying lands, but little above sealevel, with sluggish bayous separated by numerous islands clothed in a dense tropical vegetation. In these fastnesses the creatures would be comparatively safe from their carnivorous enemies, while in the quiet waters they would find support for their huge bodies both against the burden imposed by gravity and the warning pangs of hunger."

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[3] W. T. Lee: Reasons for regarding the Morrison an introductory Cretaceous formation. Bull. Geol. Soc. Am., vol. 26, 1915, pp. 308-309.

[4] C. C. Mook: A study of the Morrison formation. Ann. N. Y. Acad. Sci., vol. 27, 1916, pp. 157, 43, 158, 113-115.

[5] R. S. Lull: Sauropoda and Stegosauria of the Morrison compared with those of Europe and eastern Africa. Bull. Geol. Soc. Am., vol. 26, 1915, pp. 324-325.

RELATION TO ADJACENT FORMATIONS

The entire Morrison is a fresh-water deposit overlying the marine Sundance formation, and the opinion was general, until very recently, that the two are conformable with one another. At first sight this continuity appears to be true, and especially so in Wyoming. The Morrison is, however, a transgressing fresh-water formation over the marine Sundance and the latter, too, is a transgressing deposit over a planed floor. The apparently conformable contact between them in Wyoming must, therefore, in reality be a broken one and of the disconformable type. In the field there is rarely any difficulty in distinguishing the two formations, for the Sundance is a fairly regularly bedded series of identical materials over wide areas, is usually replete with marine fossils, especially belemnites, and with skeletons of ichthyosaurs (*Baptanodon*) and plesiosaurs; while the Morrison is composed of dissimilar sediments from place to place and the fossils are always land animals, chiefly land plants, dinosaurs, and fresh-water mollusks. The difficulty lies in ascertaining the actual line of contact between the two formations of similar shales and in the further condition that the marine fossils become scarce toward the top of the Sundance, while the dinosaur bones are usually absent in the lowest beds of the Morrison. When the Morrison begins with a more or less thick and unfossiliferous sandstone and reposes on green shales that have belemnites, oysters, or *Camptonectes,* it seems best to hold that the sandstone is at the base of the overspreading fresh-water formation. These sandstones are, however, very irregular in distribution, and when they are of no great thickness and thin-bedded, then dependence for the separation of the two formations remains with the fossils. They are always the criterion for discerning discontinuity in conformable formations, and it is by no means easy on physical evidence alone to discern a break or disconformity in such a sequence. The writer's experience in Wyoming is that the Sundance is always fossiliferous throughout, though the fossils are common only locally and mostly so in the calcareous concretions that are more apt to abound below the middle of the formation.

In a conversation with Dr. W. T. Lee, the latter pointed out that as the Morrison is more often not sharply distinguished by geologists from the underlying Sundance, it may well be that the basal sandstones and other earliest deposits now included in the Morrison will in the final analysis prove not to belong to it. Such basal deposits are now included in the Morrison because it is not yet known what else to do with them.

In regard to the contacts above and below the Sundance, Darton[6] remarks as follows:

"Although there is a long time interval between the Sundance and Chugwater [Triassic] formations, marked erosional unconformity is rare and in places it is difficult to draw the line between them. This is probably because the first sediments of the upper formation were derived from the one below. The upper limits [of the Sundance] are similarly ill defined. There is no discordance in dips of underlying or overlying formations."

Lee[7] observes that

"in most places the bedding planes of the Morrison are so nearly parallel with those of the formations above and below it that the structural relations can only be apprehended by taking a broad view. . . . In strong contrast with the unconformable relations at its base, the Morrison is obviously conformable with the beds above it. . . . There is no escape from the conclusion that the Morrison, as a formation, is structurally much more closely related to the overlying formations of Cretaceous age than it is to underlying formations."

In the opinion of Stanton,[8]

"the lithologic and stratigraphic evidence of a break in sedimentation is fully as great, if not greater, between the Morrison and the rocks of Washita age, where they are in contact, as it is between the Morrison and the Sundance in the northern area where these two formations come together."

Mook[9] now also regards the Morrison as an overlapping formation. There is an "erosion plane beneath the Morrison over most of its area," and the formation "is more closely related to the overlying than to the underlying formations." He concludes:

"It appears, then, that the Morrison commenced as a continental deposit in the western areas of its occurrence in early Comanchian time (or possibly latest Jurassic), and that it spread outward as it was built up, the uppermost and easternmost beds being laid down in [later] Comanchian time. . . . It seems probable that the Morrison merged into the marine [Comanchian] deposits" in the southeastern and eastern areas.

Description of typical Sundance and Morrison Sections

GENERAL REFERENCE

The following sections of the Morrison and Sundance formations are given to bring out the detail of the stratigraphy and the variability of the

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[6] N. H. Darton: Paleozoic and Mesozoic of central Wyoming. Bull. Geol. Soc. Am., vol. 19, 1908, p. 438.
[7] Op. cit., pp. 309-310.
[8] T. W. Stanton: Invertebrate fauna of the Morrison formation. Bull, Geol. Soc. Am., vol. 26, 1915, p. 348.
[9] Op. cit., pp. 160, 172.

deposits in Colorado and Wyoming. A presentation of all of the more important sections can be had in Mook's paper of 1916 on the Morrison.

OIL CREEK, BELOW GARDEN PARK, COLORADO

About one mile south of the Marsh dinosaur quarry. Adapted from Stanton, Journal of Geology, volume 13, 1905, page 666.

	Feet
Dakota massive gray sandstone overlain by Benton shale	100
Break in deposition.	
Comanchian (Purgatoire). Marine dark gray shales with thin-bedded sandstones. Marine fossils (Washita) 35 feet from top	85
Massive gray sandstone with conglomerate near top	35
Probable break in deposition.	
Morrison (typical). Chocolate, reddish, and variegated shales and variable sandstones. All of the dinosaurs were collected in the upper half. Associated with or just above and below the dinosaurs occur also the bivalves *Unio felchii*, *U. toxonotus*, *U. macropisthus*, *U. iridoides*, and *U. lapilloides;* the snails *Limnœa ativuncula*, *L. consortis*, *Planorbis veternus*, and *Valvata scabrida;* the ostracods *Metacypris forbesii*, *Darwinula leguminella*, etcetera. Probable total thickness	400

COMO BLUFF, WYOMING

Six miles east of Medicine Bow. Seen by Schuchert July 29, 1899.

	Feet
Comanchian. Cloverly heavy-bedded sandstone. About	45
Probable break in deposition.	
Morrison formation. Green shales with thin zones of gray and buff and beds of dark chert. In places variegated green and red shales. Toward the top appear intercalated thin sandstones. Main horizon for dinosaurs (especially *Stegosaurus*), mammals (at the very top), *Unio nucalis*, and *Vorticifex stearnsii*. About	75
Reddish shales with local sandstone zones and many ironstone concretions. Dinosaurs here also. Above, variegated with green shales. About	75
Green shales with thin beds of brown limestone, and pyrite concretions. About	20
Whitish to buff sandstone. About	15
Total (estimated)	185
Darton gives the thickness as 202 feet.	
Break in sedimentation.	
Jurassic. Sundance formation. Greenish to buff sandy shale with an abundance of *Belemnites densus* throughout. Much marked with *caudagalli*-like burrows. About	50
Coarse white sandstone	5
Buff and red sandy shale with chert horizons. Weathers rapidly. *Belemnites* at about 5 and 35 feet from base. About	50

	Feet
Coarse, heavy-bedded, buff sandstone. About	10
Green to buff sandy shale with *Ostrea strigilecula*, *Pseudomonotis* (*Eumicrotis*) *curta*, *Belemnites densus*, and *Cardioceras cordiforme*. Weathers rapidly. About	20
Red and white sandstone and red shale, passing upward into thin-bedded, white, coarse sandstone somewhat conglomeratic at the top. About	22
Total	157

Break in deposition.

Triassic. Chugwater red sandy shales between white sandstones.

FREEZEOUT HILLS, WYOMING

North of Medicine Bow. Adapted from W. C. Knight, Bulletin of the Geological Society of America, volume 11, 1900, pages 381-382.

	Feet
Comanchian. Cloverly conglomerate and sandstone. Originally called Dakota sandstone.	
Probable break in deposition.	
Morrison formation. Drab marls and clays, with some thin sandstones having dinosaurs	55
Hard clay and sandstone with naiids and teeth of crocodiles	1.5
Drab marls and clays with a few beds of calcareous sandstones. Has *Allosaurus fragilis*, *Diplodocus longus*, *Brontosaurus excelsus*, *Morosaurus grandis*, *Stegosaurus ungulatus*, *Camptosaurus dispar*, *Ceratodus*, and turtles	24.5
Drab marls and clays with thin soft sandstones	46
Yellowish soft sandstone with cycads and wood	10
Brown sandstone, cross-bedded	2
Drab shales, clays, and marls	70
Greenish sandstone	4
Total	213

Break in deposition. Knight notes this "unconformability" as "apparent" and adds that it has "not yet been detected."

	Feet
Jurassic. Sundance (Knight's Shirley) formation.	
Reddish and brown shales and clays	49
Dark limestone with *Camptonectes* and *Ostrea*	2
Greenish shales with dark bands of clay and sandstone, and many concretions replete with nests of invertebrates and an occasional *Baptanodon* and *Plesiosaurus*	50
Gray sandstone	4
Brownish shales with concretions having a few fossils	44
White sandstone with fossils at the top	30
Total	179

Break in deposition.

Triassic. Red sandstones, etcetera.

NORTHWESTERN SIDE OF FREEZEOUT HILLS, WYOMING

Seen by Schuchert July 30, 1899.

	Feet
Comanchian. Cloverly conglomerate, heavy-bedded, up to	75
In 1899 correlated with Dakota sandstone. Knight then told me he had collected here a vertebra of a marine saurian.	
Probable break in deposition.	
Morrison formation. Mainly sandstones at this locality, but from 4 to 5 miles east all has changed to green shales.	
Covered area. In places a sandy shale and in others sandstone	25
Soft, buff, cross-bedded sandstones in thick beds. About	50
Covered area. About	70
Heavy-bedded sandstone. About	15
Soft, white sandstone. About	25
Total	185
Break in sedimentation.	
Jurassic. Sundance formation. Sandy shales, green	2
Green shale with calcareous concretions, some of which have small bivalves. Main *Belemnites densus* zone. Also *Ostrea strigilecula*. About	30
Soft, buff, sandy and shaly sandstones terminating in indurated brown-stained beds. Has *Belemnites* and, at the top, nuculoids.	30
White, thin-bedded sandstones	6
White, thick-bedded and irregularly layered sandstones	75
Total	143
Break in deposition.	
Triassic. Chugwater formation. Red and green sandy shales.	

EASTERN SIDE OF FREEZEOUT HILLS, WYOMING

Near Dyer's ranch house. See W. N. Logan, Kansas University Quarterly, volume 9, 1900, pages 109-134. His section considerably altered by Schuchert, from observations made September 11, 1899.

	Feet
Comanchian. Cloverly formation. Originally correlated with the Dakota formation.	
Thin-bedded sandstone (top not seen; total thickness elsewhere about 75 feet)	10
Blue shale, hard	22
Heavy-bedded, coarse sandstone and conglomerate	10
Total seen	42
Probable break in deposition.	
Morrison formation. Jointed clay, greenish, with an occasional sandstone layer. Has sauropods, *Stegosaurus*, and *Allosaurus*	70
Arenaceous limestone, bluish to brown. *Unio knighti, U. willistoni, U. baileyi, Valvata leei,* and *Planorbis veternus*	1

	Feet
Jointed clay, greenish, with small concretions. *Brontosaurus, Diplodocus*, and *Morosaurus*. First appearance of *Planorbis veternus* and *Valvata leci*	30
Sandstone, fissile, brown	5
Jointed clay, greenish. Has single bones of sauropods	30
Sandstone, gray to brown, much cross-bedded with local zones of conglomerates. Small trunks of cycads (*Cycadella*) occur rarely and some of them in their places of growth	10
Clay, greenish, having toward the top the main level for *Brontosaurus* and *Morosaurus*. To the west more and more of these three lowest zones are replaced by sandstones attaining to 125 feet	60
Total	206
Break in deposition.	
Jurassic. Sundance formation. Siliceous limestone with *Camptonectes bellistriatus* and *Belemnites*	1
Shale, green	4
Sandstone, green, thin- and cross-bedded, with *Belemnites*	2
Shales, olive green, with lenses of thin sandstones toward the top and an abundance of calcareous concretions below. Near the top, *Ostrea strigilecula* and *O. densa*. Ten feet from top, *Cardioceras cordiforme* is most abundant, along with *Pentacrinus asteriscus*. *Belemnites densus* occurs throughout, though rare. About 10 feet above base occur many concretions replete with *Astarte packardi, Tancredia bulbosa, T. magna, Lima lata, Goniomya montanænsis, Pleuromya subcompressa, Cardinia wyomingensis, Cardioceras cordiforme*, etcetera. Just above the concretion zone occur the skeletons of *Baptanodon* and plesiosaurs. About	75
Sandy shale, greenish, with an abundance of *Belemnites*	10
Sandstone, soft, green, and yellowish, weathering into red beds. Rippled. Has many *Belemnites densus* and *B. curtus*	25
Sandstone, thin-bedded, white, with green sandy shale partings. Has bivalves and *Lingula brevirostris*	20
Sandstone, yellowish and thin-bedded	20
Sandstone, heavy-bedded	20
Total	177
Break in deposition.	
Triassic. Chugwater red beds.	

Dr. S. H. Knight, of the University of Wyoming, has during the past two summers been studying the Morrison and Sundance formations south from the Freezeout Hills to the Colorado State line, and has furnished the writer with the following information. At the north the Sundance has a thickness of 179 feet, and the greenish shales, sandy limestones, and shaly sandstones are more or less fossiliferous to the top of the forma-

tion. Twenty miles to the southeast, near Centennial, the Sundance is reduced to 156 feet and has *Belemnites densus* throughout the upper 50 feet. Five miles farther in the same direction, near Jelm Mountain, the Sundance is down to 92 feet thick and here all the higher beds with marine fossils are absent. The top of the section here consists of 50 feet of buff to cream-colored, soft, massive sandstone devoid of fossils—the same sandstone at Centennial is 85 feet thick and is beneath the fossiliferous marine Sundance—and it is this member that makes up the top of all the other sections down to the Colorado State line (north and south face of Red Mountain and at Bull Mountain). This member at Bull Mountain is 36 feet thick and shows cross-bedding of the eolian type. In other words, these sections demonstrate that the Sundance thins southward from 179 feet to 50 feet and even to 20 feet. The "thinning takes place by cutting out progressively the upper members, and apparently not by overlap but rather through erosion." This then appears to be clear evidence that an erosion interval existed after Sundance time and before the deposition of the younger transgressing Morrison. Knight also recites other evidence showing that the Morrison clearly is a transgressing formation not only over the Sundance but across the Triassic as well.

Correlation of Sundance and Morrison Formations

Opinions and Conclusion as to Age of the Sundance

It is now widely held that the Sundance sea, with a cool-water fauna, began in the later part of the Jurassic to transgress widely over Alaska and British Columbia and into the states of Montana, Idaho, Wyoming, Colorado, New Mexico, and Utah. In the Great Plains region the deposits have an average thickness varying between 200 and 400 feet, but increasing to the west to upward of 1,000 feet, and in southwestern Wyoming, it is said, to 3,500 feet. The nature of the sediments and the universal presence of oysters indicate that the sea was a shallow one, and, further, that it flowed over a land eroded to a low relief.

Stanton[10] states that the marine Sundance fauna

"belongs in the *lower* part of the Upper Jurassic. It is characterized by *Cardioceras cordiforme* and other invertebrates, which indicate approximate correlation with the Oxfordian of the European Jurassic."

Last December Stanton informed the writer that the above correlation of the

"Sundance with European formations has been made through Alaska and other boreal Jurassic areas in this way: The Chinitna formation in Alaska con-

[10] T. W. Stanton: Bull. Geol. Soc. Am., vol. 26, 1915, pp. 347-348.

tains a fauna characterized by several species of *Cadoceras*, which has been referred to the Callovian by Neumayr, Hyatt, and Pompeckj. Immediately above the Chinitna is the *Aucella*-bearing Naknek formation, 5,000 feet thick, in the lower 600 feet of which is a zone containing several forms of *Cardioceras* so closely related to those found in the Sundance that I believe them to furnish a good basis for approximate correlation. Now, if the Chinitna is Callovian, this lower part of the Naknek formation ought to be Oxfordian (and possibly Corallian). . . . On the best evidence we have, I think that the Sundance formation is somewhat later, but not very much later than Callovian."

In a letter of February, 1917, Stanton remarks further as follows:

"In the Mariposa formation of California there is *Cardioceras dubium* Hyatt, which earlier was referred to *C. alternans* by J. P. Smith (Bulletin of the Geological Society of America, volume 5, 1894, page 253), who pointed out the differences between it and *C. cordiforme*. *C. alternans* is the genotype of *Amœboceras* and is characteristic of the Lower Kimmeridgian. This *C. dubium* is probably of Lower Kimmeridge age and it is associated with *Aucella*. Now, there is no *Aucella* fauna in the Sundance, and in view of the fact that Jurassic Aucellæ are abundant in Alaska, Oregon, California, and Mexico, it seems to me that their absence from the Sundance indicates that that formation was not contemporaneous with the *Aucella*-bearing beds of the Mariposa and other formations of the west coast, but older; and the finding of Sundance types of *Cardioceras* in the Cook Inlet region beneath the lowest *Aucella* beds there is definite proof that this is so. (*Cardioceras* was found in the same formation which contained *Aucella* higher up, but the two were not found associated.) . . . Hyatt, Smith, Lapparent, and Haug have all referred the Sundance to the Oxfordian, basing their opinions on the character of the ammonites."

In March, 1917, Stanton writes that his assistant, Doctor Reeside, is studying all of the American forms of *Cardioceras* and related genera, and that he distinguishes a considerable number of forms, but does not believe any of them to belong to the *alternans* group or the genus *Amœboceras*, other than those of the Mariposa slate of California.

Under date of February 24, 1917, Prof. J. P. Smith said in a letter to the writer:

"I do not know the Sundance fauna at first hand, but only from Whitfield and Hovey's paper on it. It has no affinities with our West Coast faunas and it does not seem possible to connect it with anything in the Mariposa. I have always been inclined to regard it as Oxford."

The writer, thinking that the Morrison was of Comanchian age, and that after all *Cardioceras cordiforme* might be younger than Stanton's determination, made inquiries of his friend, Dr. S. S. Buckman, of Southfield, England. To him he sent copies of the original descriptions and figures, along with three good specimens of the Sundance ammonites. To this inquiry came the following reply:

"It is advisable to take note of the difference in British and Continental usage of the term Oxfordian (Oxford). We use Oxfordian as a synonym for Oxford Clay, which Continental writers usually call Callovian: they use Oxfordian for the higher horizon Oxford Oolites, for which we employ the term Corallian. I suggested a revision a few years ago to avoid this sort of ambiguity. This may be put in tabular form thus:

"*Old terms*	*New terms*	*Ammonites*
Portlandian	Portlandian	
Kimmeridgian	Kimmeridgian	Amœboceras
Corallian	Argovian	Cardioceras
Oxfordian	Divesian	Quenstedtoceras
Callovian	Callovian	Cosmoceras

"The ammonites you have sent me look older than *Amœboceras.* I am not prepared to differ with Haug about putting them in *Quenstedtoceras,* but I have my suspicions. However, their general character seems to point to basal Oxfordian in the Continental sense—that is, basal Corallian of the English classification. They are of earlier type than *Amœboceras.*

"Taking what Stanton says about American formations, I am inclined to suggest the following correlation:

"*European classification*		*American formations*
Portlandian	Upper	
	Lower	Naknek with *Aucella*
Kimmeridgian	Upper	
	Lower	Mariposa
Argovian	Upper	
	Lower	Naknek with Cardioceras = Sundance
Divesian	Upper	
	Lower	
Callovian	Upper	
	Lower	Chinitna"

As it is well known that the genera of reptiles are rather restricted in geological range, it is well to see what they can teach in this connection. In the Sundance occurs the ichthyosaurian *Baptanodon,* first described by Marsh and admitted by Gilmore to be closely related to the English *Ophthalmosaurus* of the Oxford Clay. Andrews[11] later reinvestigated this genus and concluded that "the English and American species may be regarded as belonging to a single genus, which must be called *Ophthalmosaurus,* that name having the priority." We may add that this reptile

[11] C. W. Andrews: Cat. marine reptiles of the Oxford Clay. Brit. Mus. Nat. Hist., part i, 1910.

is as characteristic of the Oxford Clay as its American equivalent is of the Sundance.

In regard to the four or five species of plesiosaurs from the Sundance (*Megalneusaurus, Cimoliasaurus, Diplosaurus,* and *Plesiosaurus*) (*Pantosaurus* may be the same animal, and this genus, according to Andrews, is "clearly identical with *Muræenosaurus* of the Oxford Clay of England"), Williston[12] says:

"These species all agree in having single-headed cervical ribs, and broad and short epipodials. From a somewhat careful study of the literature of English plesiosaurs, the earliest recorded occurrence of forms with single-headed cervical ribs that I can find is in the Oxford Clay [= Oxfordian of Buckman], as is also the earliest of the short epipodial forms. One species described from the Baptanodon [= Sundance] beds and referred to *Cimoliasaurus* (to which it probably does not belong) has three epipodial bones, as I am satisfied from an examination of the type specimen. The earliest European species having three epipodials, so far as I can ascertain, is from the Kimmeridge. All these characters are specializations, which became predominant in the Cretaceous, the elongated epipodials utterly disappearing. . . . The conclusion, therefore, to be derived from the plesiosaurs is that the beds are not older than the Kimmeridge. This conclusion is, of course, not decisive, as it may be that such specialization will yet be found in older forms in Europe, and since we can conceive of a more advanced evolution of the plesiosaurs in the western continent during these times."

The conclusion to be derived from these opinions is that the marine animals of the Sundance formation are indicative of about the age of the English Oxford Clay near the top of the Oxfordian, or rather Divesian, and the earlier part of the succeeding Argovian. There still remains of the Jurassic, therefore, some of the Argovian and all of the Kimmeridgian and Portlandian, which together may have a thickness in England of 1,000 feet and on the continent a considerably greater one. The question to be answered is, then, Does the Morrison, which is clearly separated by a break from the Sundance, still fall into this Upper Jurassic time, or is it of earlier Comanchian time, but older than the Washita equivalent (Purgatoire) that overlies it?

AGE OF THE MORRISON

General statement.—Let us now see what the fossils that are entombed in the Morrison teach. There have been described about 158 species, as follows (slightly altered from Osborn):[13]

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[12] S. W. Williston: The Hallopus, Baptanodon, and Atlantosaurus beds of Marsh. Jour. Geology, vol. 13, 1905, p. 342.

[13] H. F. Osborn: Close of Jurassic and opening of Cretaceous time in North America. Bull. Geol. Soc. Am., vol. 26, 1915, p. 299.

Land plants	23	Rhynchocephalians	1
Fresh-water mollusks	24	Dinosaurs	75
Practically all belong to living genera.		Theropoda	15
		Iguanodonts	14
Fishes	3	Armored forms	11
Pterosaurs	1	Sauropoda	35
Turtles	1	Birds	1
Crocodiles	3	Mammals	25
Frogs	1		

Of these fossils the only ones that can be used more or less successfully in detailed correlation are the plants and dinosaurs. This is because they have representatives, and in some abundance, in more than two places, while the other vertebrates are too scattered, often occurring in single examples, to be of much value in stratigraphy.

Evidence of the plants.—Recently a few additional land plants other than those mentioned above were found in the Morrison of the Big Horn Basin of Wyoming. These Knowlton has determined as *Nilsonia nigricollensis,* a Lakota species, and *Zamites arcticus,* of the Kootenai, both of which formations are younger than the Morrison. He states:[14] "So far as they go they indicate that the Morrison is Cretaceous." On the other hand, the small cycad (*Cycadella*) trunks found by Knight in the Freezeout Hills, when compared with those from the Lakota and Patuxent formations, Knowlton holds also argue for the Cretaceous age of the Morrison.

Berry,[15] from a detailed study of the interrelations of the plants of the Wealden, Potomac, Kome, Kootenai, and Morrison formations, concludes that "at least some of the Morrison must be of Lower Cretaceous age." The plants are therefore seen to be in favor of the Morrison being of Comanchian age, though the evidence is not decidedly in favor of the correlation.

Evidence of the invertebrates.—It is well known that the fresh-water mollusks have little significance in correlation, and this appears to be especially true of those of the Morrison. Stanton[16] has studied these shells and concludes:

"The Morrison fauna then stands by itself, distinct from the few fresh-water invertebrates that preceded it in the Triassic and distinct from the non-marine Cretaceous faunas which followed it. . . . The study of these

[14] F. H. Knowlton: Note on a recent discovery of fossil plants in the Morrison formation. Jour. Wash. Acad. Sci., vol. 6, 1916, pp. 180-181.

[15] E. W. Berry: Paleobotanic evidence of the age of the Morrison formation. Bull. Geol. Soc. Am., vol. 26, 1915, p. 341.

[16] Op. cit., pp. 347-348.

[underlying and overlying] marine faunas serves to fix definitely the time limits within which the Morrison must fall."

"The Morrison must be older than Cenomanian and probably younger than Oxfordian. That it represents all of this interval is not probable. . . . So far as stratigraphy and invertebrate faunas are concerned, the Morrison is somewhat more likely to belong to the Jurassic portion of the interval just indicated than to the Cretaceous portion; but their evidence is not conclusive on this point."

Evidence of the dinosaurs.—In his study of the Maryland Lower Potomac (Arundel formation) reptiles, Lull[17] says that they

"compare very closely" with those of the Morrison, "and, in some instances, very closely allied if not identical species are found in the West. A striking similarity also prevails between the Potomac on the one hand and the Wealden of Europe on the other." Further, the Arundel formation correlates "absolutely with the Morrison of the West. . . . The weight of this evidence would seem to place this fauna beyond the Jurassic into the beginning of Cretaceous times."

To these statements should be added that now all of the Potomac is regarded as of post-Jurassic age and in the main Comanchian. In a later paper, however, Lull[18] modifies his conclusions as follows:

"Correlation based on the sauropod evidence between Europe and America is not to be relied on at present, but we can evidently point to the middle [and the upper dinosaur] Tendaguru horizon of East Africa, which contains the genus common to the Morrison, as homotaxial with the latter."

Osborn[19] states that among the carnivorous and the large herbivorous dinosaurs there are

"forms resembling those which range from the Oxfordian through the Kimmeridgian into the Purbeckian and even into the Wealden. In general, it is said the Morrison dinosaurs are more specialized than those which have been found in the true British Jurassic formations, but there are some very striking exceptions. . . . All the camptosaurs of the Morrison are more generalized and primitive in structure than the iguanodonts of the Wealden. . . . The mammals appear to be closely related in their stage of evolution with those of the Purbeckian of England. . . . Geologically the stratigraphic relations certainly appear to favor Lower Cretaceous, or Comanchian, age for large portions of the Morrison."

Correlations.—As long as the Morrison was held to be intimately united with the Sundance and in unbroken connection with it, it was natural to regard the former as of Upper Jurassic time, and this conclusion was all

[17] R. S. Lull: The Reptilia of the Arundel formation. Maryland Geol. Surv., Lower Cretaceous, 1911, pp. 173, 178.

[18] R. S. Lull: Bull. Geol. Soc. Am., vol. 26, 1915, p. 334.

[19] Op. cit., pp. 298-301.

the more legitimate, since previous to fifteen years ago European stratigraphers were unanimous in regarding the Wealden as of the same time. Now the Wealden is regarded by all stratigraphers as of the early Lower Cretaceous, and because of this reference and the similar nature of the Morrison and Wealden faunas, some American vertebratists are holding that the Morrison straddles the time from the later Upper Jurassic well into the Comanchian. This view is best expressed by Osborn as follows:[20]

"It will probably appear as the chief result of this symposium that the intermediate theory is correct; that . . . the Morrison sedimentation was a very comprehensive and wide-spread process; that it began in certain localities earlier than in others, namely, during Upper Jurassic times; that it extended well into Lower Cretaceous times; that all the sediments known as Morrison represent a vast period of geologic time in which sedimentation was remarkably slow, because at no point does this so-called formation . . . attain any considerable thickness. The more primitive forms of Morrison life are partly, at least, truly Jurassic, while the more specialized progressive maybe are truly Lower Cretaceous."

Osborn refers to this view as having been first maintained by Williston, but the latter was treating of the Atlantosaurus beds, as they finally came to be known, a series of strata that embraced more than the Morrison. Accordingly, in 1905, Williston[21] showed that the strata affording *Hallopus* and *Nanosaurus* have no connection whatever with the Atlantosaurus or Morrison formation, but that they clearly belong in the Upper Triassic. Further, that at Lander, Wyoming, in the top of the Atlantosaurus beds, occur fish and reptilian remains like those in the Mentor formation of Kansas, the equivalent of the Washita formation of the Upper Comanchian of Texas. In other words, that the marine Comanchian Purgatoire formation of central Colorado extends as far as Lander, Wyoming.

Williston[22] is of the further opinion that

"there is no valid vertebrate evidence pointing to an age greater than the Purbeck for the Atlantosaurus beds, and but very little for a greater age than that of the Wealden." "The upper part of the Atlantosaurus beds is, it seems to me, indisputably Cretaceous [now the Purgatoire of Colorado and Cloverly of Wyoming]; the lowermost part [after removing the Hallopus horizon] is probably not older than the Wealden, though possibly of Purbeckian age [the very top of the English Jurassic]. I therefore strongly protest against the common usage of referring all the fossils from these beds to the Upper Jura. . . . The only proper designation for the composite faunas included in them is Jura-Cretaceous; this assumes that the Wealden is really Jurassic," but now the opinion is that the Wealden is Lower Cretaceous in age, an alteration in favor of taking the Morrison out of the Jurassic.

[20] Op. cit., p. 302.
[21] Op. cit., pp. 338-341.
[22] Op. cit., pp. 347-348.

Until 1905 the Morrison was held to be overlain by the Dakota, the basal deposit of the great Cretaceous invasion. In that year, however, Lee and Stanton found that the Comanchian seas overlapping from the Gulf of Mexico northward into Kansas and Colorado spread over the Morrison in Washita time, and that the latter in turn was overlain by the Cretaceous (Coloradoan series). This relation, Stanton writes,[23]

"was seen on Purgatoire River south of La Junta, Colorado; on the Cimarron from Garrett, Oklahoma, to the neighborhood of Folsom, New Mexico; on the Canadian north of Tucumcari, New Mexico; and finally in Garden Park, near Canyon City, Colorado, at the noted locality for Morrison vertebrates."

In parts of Wyoming the Morrison is disconformably overlain by the Cloverly, also regarded as of Comanchian age, for it lies beneath the Benton shales of undoubted Cretaceous time, there being no Dakota sandstone here.

Finally, Lee[24] regards the Morrison as not only of Lower Cretaceous time, but even as "late Lower Cretaceous." He comes to this correlation because of what he regards as the intimate stratigraphic relation of the Morrison to the higher Purgatoire formation and the paleophysiography of the time of its origin.

Conclusions.—From the evidence presented, it is clear to the writer that the fresh-water Morrison deposits not only overlie the marine Sundance, but that the former is a transgressing formation and is separated from the latter by a time break or disconformity. How long this erosion interval lasted is not yet ascertainable from the physical evidence, nor will the fossils directly answer this question, because they are unlike criteria, since those of the Sundance are of a marine habitat, while those of the Morrison are of the land. However, the fossils of the Sundance indicate clearly that they are not at all of the latest Jurassic, but rather that enough time was left in this period for the deposition of the Morrison. Against the conclusion that the Morrison is of Jurassic age are the views of the paleobotanists and those of the American vertebrate paleontologists. On the other hand, if we depend wholly on the correlations of the Germans regarding the Tendaguru succession, then the Morrison appears to straddle the interval between the Upper Jurassic and the Lower Cretaceous. That we are not obliged to accept this view is borne out by the suggestion of Buckman (see page 278), who would refer the Upper Dinosaur zone of the Tendaguru also to the Jurassic, because it is intimately connected with the *Trigonia smeei* zone of late Kimmeridgian time.

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[23] T. W. Stanton: The Morrison formation and its relation with the Comanche series and the Dakota formation. Science, new ser., vol. 22, 1905, p. 756.

[24] Op. cit., p. 305.

Accordingly, it would appear that as the dinosaurs of the Morrison and those of the Middle and Upper Dinosaur zones of the Tendaguru series are so much alike, far more so than those of the Morrison and Wealden, all of these deposits, other than the latter, are of Upper Jurassic age. This, then, is a return to the older view that the Morrison is Upper Jurassic in time—a conclusion that surprised the writer. That the Wealden, however, is of Lower Cretaceous age is a conclusion now established in the known transgression of these fresh-water deposits over Jurassic and older rocks and their upward connection with marine beds of acknowledged early Cretaceous age.

The Tendaguru Series

DISCOVERY

It was in 1907 that the late Prof. Eberhard Fraas, of Stuttgart, made the very interesting discovery of great sauropod dinosaurs in southern German East Africa, which then and for some years afterward were thought to be larger by far than those of America. His discovery stimulated the University of Berlin to undertake an exploration of the field on a large scale, and now the final results are published, in so far as the stratigraphy and the invertebrate faunas are concerned.[25] We now know that there are three brackish- to fresh-water dinosaur horizons interbedded with three zones more or less replete with marine mollusks, and of these, two indicate very clearly their own age as well as that of the interbedded dinosaur horizons. As these age-determined dinosaurs appear to be much like those of the American Morrison formation, whose time in the geological scale is not fixed, it is desirable to present a summary of the African studies, at least in so far as they bear on the age of the Morrison and the habitats of these reptiles. A preliminary statement of the African discovery was presented by the writer in 1913.[26]

GENERAL RESULTS

The director of the Geological-Paleontological Institute of the Royal Museum in Berlin, Professor Branca, informs us that the expedition to

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[25] Wissenschaftliche Ergebnisse der Tendaguru-Expedition 1909-1912. Published in Archiv für Biontologie, Berlin, vol. iii. Part i, 1914, pp. 1-110, has six papers of a general nature by Wilhelm Branca and W. Janensch. Part ii, 1914, pp. 1-276, has four papers on the geology, stratigraphy, geomorphology, tectonics, and peat-moors, by Edwin Hennig, H. von Staff, and W. Janensch. Part iii, 1914, pp. 1-312, has six papers on the invertebrates and fishes by W. Janensch, J. Zwierzycki, W. O. Dietrich, Edwin Hennig, and Erich Lange. For the work on the armored dinosaurs, see Hennig, Kentrosaurus æthiopicus der Stegosauride des Tendaguru, Sitz. d. Gesell. Naturf. Freunde zu Berlin, 1915, pp. 219-247.

[26] C. Schuchert: The dinosaurs of East Africa. Am. Jour. Sci. (4), vol. 35, 1913, pp. 34-38.

the southern part of German East Africa was led by Dr. Werner Janensch, assisted by Doctors Hennig, Von Staff, and Reck, during the years 1909-1912. During this time in the dry season they always employed from 150 to 500 natives, whose wages averaged about twelve cents a day. The shipments to Berlin totalled 1,050 cases, weighing about 250 tons, the whole costing about $58,000. No complete single skeleton was found, though the museum hopes to mount from four to five great sauropods, one or more small ornithopods, and one armored predentate. Of large skulls, they have found three fairly complete ones and the back parts of eight more, and of small skulls there are six. Of marine invertebrate fossils there is a great and varied quantity, and most of these are carefully collected as to horizons.

GENERAL STRATIGRAPHY

Branca[27] tells us that

"even now we have attained the important conclusion that the dinosaurs of German East Africa belong to the Upper Jurassic and the Lower Cretaceous, and accordingly these animals lived not later than those [of the Morrison] of North America." The invertebrate and fish faunas interbedded with the dinosaur zones establish the conclusion "that the saurian beds are not actually continental deposits . . . but are also deposits of waters of a nearby shore; but laid down under especial conditions that can be determined, at least to a certain degree, from the inherent character of the formation."

For easy reference the writer will insert here a table of the succession as determined in the area about Tendaguru:

		Mikindani fluviatile sands and conglomerates. Great break in section.
Lower Cretaceous		*Makonde* unfossiliferous series, 617 feet thick. To the north has marine Urgonian and Aptian fossils. Probable break in sedimentation. *Tendaguru* series, 400 feet.
	Neocomian.........	Marine *Trigonia schwarzi* sandstones, 16 feet. Upper or main dinosaur limy-sandy clay, 130 feet. Dinosaurs, Morrison-like.

[27] Op. cit., part i, p. 68.

Upper Jurassic	Kimmeridgian	No break in sedimentation. Marine *T. smeei* sandstones, 65 feet. Middle dinosaur limy-sandy clay, 50 feet. Dinosaurs, Morrison-like. Best skeletons here.
	Exact age not yet established	Marine Nerinea sandstones, 80 feet. Lower dinosaur sandy clay, 65 feet.
		Ancient granite and gneiss. Possibly Precambrian in age.

The Tendaguru series of brackish- to fresh-water shales and shallow-water marine sandstones, together a little over 400 feet thick, overlaps an old gneiss-granite foundation, possibly of Precambian age; all are fully described by Janensch and Hennig in Parts I and II of the German publication. The series is exposed in southern German East Africa in an east and west direction for at least 27 kilometers and north and south for over 100 kilometers. The deposits were laid down between hills and islands of granite. At the base the Tendaguru series is marked by a great unconformity, and on it lies the Makonde formation, and all are to be seen on the high plateaus and in the many deep ravines cutting through them. The three marine zones, together 130 feet thick, are hard, coarse-grained, or even conglomeratic (arkosic), cross-bedded sandstones, with the fore-setting toward the east and northeast, and this feature is in harmony with the general dip, which is in the same direction. The dinosaur zones consist in the main of greenish shales, though certain beds are brick-red in color. The latter color appears to be due to secondary causes, as weathering or the percolating of aerial ground waters. In places the dinosaur shales become sandy and are then also cross-bedded, rippled, and have some intraformational shale pieces. Nowhere do the authors mention the presence of sun-cracking. The Makonde variegated red and white muddy sandstones are unfossiliferous, 617 feet in thickness, and are said by Hennig to lie unbroken on the Tendaguru series. Beyond the Tendaguru region the Makonde formation becomes abundantly fossiliferous and the fossils correlate the sandstones with the Urgonian and Aptian, or, in other terms, with the Lower Cretaceous. It would therefore seem that the Makonde is also an overlapping formation and toward the southwest. This feature indicates to the present writer that there is in all probability a break in deposition between it and the Tendaguru series, at least in the Tendaguru area. Unconformably over the Makonde series are the very young Mikindani beds of fluviatile sands and conglomerates (*Schotter*).

Hennig[28] is convinced that there is no break in deposition in the Tendaguru series, and that the three dinosaur horizons are intimately united by transition zones with the three interbedded sandstones that are clearly of marine origin. The transition zones are proved to be such not only by their petrographic nature and transitions, but by their included faunas as well. The whole consists of both marine and brackish-water deposits, though the latter in the proximity of rivers may have been completely of fresh-water origin. Ammonites persist longest in the transition zones, but most often it is the guards of belemnites which occur, and they may be as common as the associated dinosaur bones. Hennig writes:[29]

"The vanishing of the generally varied and rich life of the marine horizons is somewhat sudden toward the dinosaur zones. There appears to be a remarkable loss of marine forms: aside from a very few molluscs, there are only belemnites, and these persist into the base of the dinosaur zones. They, too, then disappear, and of marine inhabitants that go to disprove the continental origin of the dinosaur beds there are, besides [ganoid] fishes, a few [brackish-water] bivalves. Of these quite a number were found, but this is mainly due to the extensive quarrying for dinosaurs. We have here a *Mytilus* and one or more species of *Cyrena*. The former is a marine shell, while the latter is a brackish-water genus, though both may occur in either habitat." "In particular abundance and at times in colonies so as to make entire beds within the dinosaur zones occur cyrenas and less commonly *Mytilus*. The former are especially common at the base of the upper dinosaur zone, and the latter at the base of the middle dinosaur zone. . . . In the transition beds between the Nerinea and middle dinosaur zones, and even at the base of the latter, in connection with skeleton p, were associated nests of [marine] snails. Locally throughout the upper dinosaur zone occur very rarely genera of [pulmonate] snails. . . . Highly interesting was the occurrence of a small marine fauna located within the ribs of a great sauropod at Mtapaia. This skeleton was found at the top of the middle dinosaur zone, practically in the transition bed, for immediately above it came the hard sandstone of the *Trigonia smeei* horizon, rich in marine shells." In fairly typical dinosaur clay there was found, in one case only, a single bone overgrown with oysters.

In the marine zones the species of *Trigonia* play an important part and are good guide fossils if one takes the time of their greatest individual abundance as the zonal marker. The species themselves may have a long time range, passing even into other zones (*T. smeei* is rare in the *T. schwarzi* and Nerinea zones), but the time when they make up whole beds of shells occurs but once. The gastropod *Nerinea* is often abundant, but is not a trustworthy guide.[30] Dinosaur bones are of very rare occurrence

[28] Op. cit., part iii, pp. 164-166.
[29] Op. cit., part ii, pp. 17-18.
[30] Hennig: Op. cit., part ii, pp. 15, 16.

in the marine horizons, and when such are present they are isolated bones that have been washed in from lower beds.[31]

SECTION IN DETAIL

The following detailed section is compiled in the main from Janensch and relates to the immediate area of Tendaguru Hill:

Tendaguru series.

(1) Upper sandstones with *Trigonia schwarzi*. Thickness at least 5 meters, but the top is not seen.

The upper 4 meters or more consist of yellowish brown sandstone that has silky bedding surfaces, with calcite crystals and bullet-like concretions up to the size of a human head. When these beds are calcareous they hold a rich marine fauna.

Lower, coarse, whitish sandstone, about ½ meter thick. The material is an arkose of sharp or rolled quartz, feldspar, and granite pieces (up to several centimeters across), cemented by carbonate of lime. The fauna in the main consists of thick-shelled mollusks and numerous corals.

The following described species occur in the *T. schwarzi* zone, those in italics being guide fossils:

Cephalopoda: 32 species, of which 19 are either new or can not be identified. *Belemnites pistilliformis*, *B.* aff. *subfusiformis*, *Duvalia* (*D. elegantissima*, new), *Nautilus pseudoelegans*, N. cf. bouchardianus, *N.* cf. *neocomiensis*, N. expletus, *Phylloceras* aff. *infundibulum*, *P. serum perlobata*, *P. deplanatum* (new), Lytoceras, *Astieria* (4 spp.), Holocostephanus, Holcodiscus (2 spp.), *Hoplites* cf. *neocomiensis*, *Crioceras* aff. *duvali*, *C.* aff. *meriani*, *Hamulina* cf. *quenstedti*, *Bochianites*. None of these species occur below in the *Trigonia smeei* zone.

Gastropoda: 17 species. Solarium, Pleurotomaria, *Trochus brancai*, Tectus, Chrysostoma, Natica, Mesalia, Omphalia, Nerinea, Nerinella, Cerithium, *Chenopus eurypterus*. None are from lower zones.

Bivalves: Of species listed by Lange there are 83 in 37 genera. From 20 to 50 per cent are related to Mediterranean forms. Of these may be mentioned *Gervillia dentata* (also occurs below), *Camptonectes striatopunctatus*, *Syncylonema orbiculare*, *Hinnites*, *Cyprina*, *Exogyra couloni*, *Modiola æqualis*, *Cucullæa gabrielis*, *Trigonia schwarzi*, *T. smeei* (rare here, from below), *T. transitoria*, *T. conocardiiformis*, *Sphæra cordiformis*, *Pholadomya gigantea*, *Panopæa gurgitis*, *Protocardia schencki* (from below), and *Vola atava*.

Brachiopoda: *Rhynchonella rauffi*, *Zeilleria dubiosa*, and *Kingena transiens*.

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[31] Hennig: Op. cit., part iii, p. 164.

(2) Upper or third dinosaur zone. Limy-sandy marls. About 40 meters. This is the most widely exposed zone of the Tendaguru.

Gray sandy marl, 2 meters.

Usually intensely red sandy marl, 5 meters.

Light yellowish gray, very soft sandstones, with zones of sandy marls, 10 m.

Red sandy marls rich in clay, 2 m.

Yellowish gray soft sandstone, 1.5 m.

Red sandy marl rich in clay, about 5 m.

Gray and reddish sandy marl, about 4 m. Has saurians.

Gray sandy marl with occasional interbedded sandstones and a basal red layer, about 5 m. Has saurians.

Transition zone. Gray sandy marls that often pass into soft sandstones with local accumulations of bones, and occasionally with marine fossils, as belemnites, 3 meters thick.

The following Sauropoda occur in this zone: *Gigantosaurus africanus* (most closely related to American *Diplodocus*), *G. robustus*, *Brachiosaurus brancai* (this genus also in the American Morrison), *B. fraasi*, *Dicrœosaurus sattleri* (this genus seems to be closely related to *Brontosaurus* and *Diplodocus*). Here also are armored dinosaurs related to the Wealden *Omosaurus* and *Polacanthus*, and, rarely, Theropoda. Isolated crocodilian teeth, along with those of selachians (*Orthacodus*) occur near the base of this zone, and here are remains of the ganoid *Lepidotus minor*, a Wealden form. Fresh-water snails are very rare. *Physa tendagurensis* was found associated with *Mytilus* cf. *galliennei* and *Cyrena*. At the base of the zone *Cyrena* occurs in colonies. A fruit from this zone is regarded by Potonié as of Wealden age.

(3) Middle marine sandstones with *Trigonia smeei*. About 20 meters thick. (Hennig states that over a wide area occur more or less large lenses of oolite formations that in one place attain a thickness of 60 meters (page 17). These oolites hold the position here indicated.)

Soft, fine-grained, olive-colored (when weathered) sandstone, 1 m.

One bed of light-colored, hard, limy sandstone that is coarse-grained to conglomeratic. Has flat and rounded feldspars up to several centimeters long. 1 m.

Soft yellowish sandstones, 4.5 m.

One hard, gray, fine-grained, limy sandstone with small well-rounded pebbles of quartz, 0.5 m.

Grayish yellow, thin-bedded, somewhat slaty, fine-grained, limy sandstone, 5 m.

Hard, gray, coarse-grained, limy sandstone with larger well-rounded quartz and feldspar pieces, 0.25 m. Toward southeast changes into an oolite. Rich in fossils, and particularly in thick-shelled mollusks and corals. *Trigonia smeei* especially common.

Yellow soft sandstones, 8 m.

The following described species occur in this zone, those in italics being regarded as guide fossils:

CEPHALOPODA: 9 species, of which 3 are new. Belemnites, cf. alfuricus, *Phylloceras silesiacum, Haploceras elimatum, H. kobelli, H. dieneri*, Craspedites, and *Perisphinctes bleicheri*. None of the species pass upward and of the genera only Belemnites and Phylloceras.

GASTROPODA: 8 species. Rhytidopilus, Pleurotomaria, Trochus, Pseudomelania, *Nerinea hennigi*, Nerinella credneri (comes up from below), and Alaria.

BIVALVES: Apparently but few of the species are described. The more characteristic forms are *Trigonia smeei* (goes upward), *T. ventricosa, Gervillia dentata* (goes upward), *Eriphyla herzogi, Protocardia schencki* (goes upward).

BRACHIOPODA: *Terebratula carteroniana.*

(4) Middle or second dinosaur zone. Limy-sandy marls. About 15 meters thick. This zone has the best dinosaur skeletons. In one quarry at Kindope about 15,000 separated small bones were secured, with an occasional sauropod bone. Here also were six incomplete skulls.

Red sandy marl, 3 m.

Alternating gray and red sandy marls with saurians, 12 m.

The following Sauropoda occur here: *Brachiosaurus brancai* (also in upper dinosaur zone, but the type specimen here), *B. fraasi* (also in upper zone, but type here), *Dicræosaurus hansemanni.* Two species of armored dinosaurs related to *Omosaurus* are very common; one is described as *Kentrosaurus æthiopicus*. Small ornithopods related to *Nanosaurus* (Morrison) and *Hypsilophodon* (European) are very common. In the uppermost and lowermost strata occur rarely six species of marine gastropods, among them *Nerita* cf. *transversa*, and three species of *Pseudomelania* (*Oonia*).

Just beneath the *T. smeei* zone at Mtapaia and located between the ribs of a great sauropod were found *Thracia incerta, Pholadomya* aff. *protei, Pleuromya tellina, Protocardia schencki, Astarte* cf. *supracorallina, Trigonia* of *costata* group, *Cucullæa irritans, Modiola perplicata, Ostrea, Gryphæa bubo, Pecten* (*Entolium*) aff. *cingulatus, Inoceramus* (*Anopæa*), *Pseudomonotis tendagurensis, Perisphinctes.* Hennig[32] says the horizon is rather Upper Kimmeridgian or even Portlandian. *Mytilus* cf. *galliennei* occurs in colonies at the base of this zone; and in association with sauropod p was found a nest of gastropods (indicated above), one *Trigonia*, columnals of crinoids and a few *Cyrena.* Elsewhere *Mytilus* cf. *galliennei.*

(5) Lower or Nerinea sandstones. About 25 meters thick.

Yellowish, fine-grained, soft, somewhat limy sandstone, 6–7 m.

Thin-bedded, fossiliferous, hard, gray, limy sandstone with scales of graphite.

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[32] Op. cit., part iii, pp. 184-185.

Gray, limy sandstone with undecomposed feldspars and plant remains, or an arenaceous limestone with fossils. Locally Nerineids.

One bed of hard, gray to brownish gray, limy sandstone with scales of graphite and light and dark mica.

Fine-grained gray limy sandstone with an abundance of foreign (conglomeratic) clay and clay-sandy inclusions.

Soft, yellow, thin-bedded sandstones that are fossiliferous at the top.

The following described species occur in this zone, those in italics being regarded as guide fossils:

Cephalopoda: 6 species. Nautilus sattleri, N. latifrons (new), Haploceras priscum (new), *Perisphinctes sparsiplicatus*, P. cf. achilles, P. staffi (new).

Gastropoda: 8 species. Patella, Lissochilus, Natica, Ampullina, Pseudomelania (Oonia), and Nerinella credneri (comes from below and is also present in the higher *T. smeei* zone).

(6) Lower or first dinosaur sandy marls. Thickness over 20 meters. Gray and red sandy marls devoid of lime. Has very small dinosaur bones and rarely *Cyrena*. Actual contact with granite and gneiss obscured.

CONCLUSIONS AS TO HABITS AND HABITATS OF AFRICAN DINOSAURS

In the lowest dinosaur horizon, which Branca refers to "the end of Jurassic time," the saurians are said to be "very small animals." That is all that we know of them as yet! In the middle and upper zones, which he states pass in age from the Jurassic to the Lower Cretaceous, the sauropods attained great size and *Brachiosaurus brancai* was the largest of all known land animals, certainly exceeding in weight and stature the American *Brontosaurus* and *Diplodocus*. The skull is about the size of that in *Diplodocus*, but as the skeleton is not yet mounted the dimensions cannot be given. The femur attains to 9 feet (2.8 m.) in length. Branca believes that these animals attained great age, and their bones became more solid with growth. Because of the small head and consequent small eating apparatus, they must have subsisted, relative to their great size, on small amounts of food. It may be that they got more nourishment and lime for their skeletons out of what they ate than is usually the case in animals, and to this faculty may be due their size. In this connection Branca says:[33]

"We will probably come nearest the truth if we assume not one cause, but rather a number of circumstances, that led to the great size of the Sauropoda: great age combined with a long growth period; also very great powers of digestion and assimilation of the food; and that these in connection with sluggish habits led to the economy of the food materials."

[33] Op. cit., part 1, pp. 76-78.

Doctor Janensch regards the shale dinosaur zones as the mud deposits of very shallow-water lagoons formed behind bars of sand, and at ebb-tide exposed to the air. Proof of this he sees in the presence of many armored dinosaurs and ornithopods that were mired in the upper dinosaur zone and especially in the middle one. These were animals of the dry land that had wandered out over the tidal flats, where they were drowned, and later on their carcasses floated about for a time before they sank to the bottom. In addition there are local accumulations of ganoid remains and driftwood bored by *Teredo,* all, he thinks, the materials of the strand. In the deeper waters farthest away from the land, there will accordingly occur the more complete skeletons and only rarely the disjointed distal parts, while nearer the shore will be found commonly the limbs, scattered bones, and connected sections of the necks and tails.

"The occurrence of such larger skeletal parts, the usual condition in the Tendaguru, speaks unmistakably for deposition in very shallow waters that were moved about by the action of the waves." [34]

In quarry X of the upper dinosaur zone almost all of the bones of sauropods are of the feet, with rarely other single bones present. In quarries IX and XVI of the same horizon nearly all the sauropod remains consist of legs, shoulder blades and pelvis, and almost nothing of the body or neck. In these places eighteen to twenty femora were secured. Such occurrences Janensch holds are due to continued assorting by the waves and currents. In further support of this conclusion he states that the ends of the leg bones show considerable wear due to rubbing by the embedding sands, and this is not the case when they occur in the clay. In three cases they got bodies with the ribs still attached, but in none were the tails present.

"As a rule, the sauropods occur in single bones and small skeletal parts, but often several individuals of the same species are found together over a limited space. Even though other species may be associated, yet one gets the impression that the sauropods also were destroyed in a catastrophe and embedded in troops."

Janensch holds it is probable that they were mired and drowned by the returning tidal flood and then washed apart by the waves. As evidence of miring he cites the occurrence of complete feet of Sauropoda standing vertically and articulated in the mud and the more distal but completely articulated parts of the legs lying prostrate. In other cases where there was an abundance of material the bones of the feet were rare or absent.

[34] Op. cit., part ii, pp. 239-240.

Of *Brachiosaurus brancai* one humerus 2 meters long, the proximal half of the associated ulna, and a tibia stood vertically in the strata, while most of the skeleton lay near by, but more or less dismembered. Some of the bones were much corroded and bitten or chewed. It is therefore certain "that the Sauropoda had been mired by their feet in the [tidal] muds." Accordingly, we must assume that these animals did not live fully immersed in the water, for they would not have been mired if they had been thus suspended in the water. They wandered out over the mud flats, were mired, and then destroyed by the returning tides. On the other hand, in the sandstones their bones are rare, and in such places no mired feet or vertically standing bones were found.[35]

Of ornithopods, Janensch says there is but one occurrence in the Tendaguru. This is in the middle dinosaur zone at Kindope and is a form related to the American Triassic genus *Nanosaurus*. Here was found a veritable bone-bed, with the parts rarely in articulation, and all of it was taken up in mass, though it required several years to do this. No entire skulls were seen, only fragments, and while all the bones of the skeleton are present and in excellent preservation, distal parts are in greatest abundance. Femora, tibiæ, and fibulæ, and the whole bone-bed as well, lay ordered in the main in a northwest-southeast direction. Of individuals there must have been many dozens present, and associated there were also a few bones of armored dinosaurs and of a small sauropod. "Such an occurrence can have but one interpretation, namely, that a great herd was killed by some catastrophe in the place of their burial." To the present writer, however, this is clear evidence not of death in the place of burial, but of drowning in the river valleys at times of freshets, and hence the transport and assorting in the direction of the stream currents.[36]

In this connection, the writer calls attention to the wonderful entombment of hundreds of small ancestral camels in a fine-grained sandstone, 60 to 80 feet thick, of fresh-water origin and of Lower Harrison age (Miocene) in the Niobrara Valley of Sioux County, Nebraska. The preservation is very perfect, the skeletons being still articulate, and "the hyoids and the cartilaginous ribs in many instances being present. A survey of this plan [plate 41] results in further confirming Doctor Loomis' statement of the possible origin of interment of this material—that is, the herd of animals meeting with a catastrophe up the stream, their carcasses floated down and found lodgment in the backwater of some large cove in which sands were accumulating. . . . *Stenomylus* is

[35] Op. cit., pp. 242-255.
[36] Op. cit., part ii, pp. 248, 256-258.

almost exclusively the only material so far found in this quarry . . . [and it] was perhaps an upland form." [37]

Of armored dinosaurs there were found single bones in more than twenty places. In only two cases, however, were found great aggregations, one in the middle, the other in the upper dinosaur zone. The richest place was at Kindope, in the middle dinosaur zone. Here occurred the bones of about thirty armored dinosaurs of varying sizes, all closely packed together and in horizontal position. There are almost no articulating parts, only a few of the vertebræ remaining in association. There is almost nothing of skulls (only back parts of three and a single tooth) or of feet. All appear, according to the Berlin workers, to have been stuck in the muds, killed in herds, and later, on the return of the tides, washed on the shore as a bone-bed.[38] Again, the present writer holds that this is evidence of river action rather than marine wave work.

The habits of the dinosaurs, and especially of the sauropods, Janensch thinks were only partly amphibious, similar to those of the living hippopotamus, for their feet show no modifications for swimming, but are like those of other animals that have not abandoned walking over the dry land. As for the habitats of the armored dinosaurs, there is as yet no unanimity of opinion whether they are of the dry land or living mainly in water. The dinosaurs, Janensch holds, were in the main land animals and in their migrations over the tidal flats were killed catastrophically, and therefore the place of their present occurrence is not their normal habitat.[39]

In the marine sandstones all of the mud was removed by the waves and currents, as is the case in normal marine deposits along a deepening shelf sea. The marine waters three times became deeper and passed over the bars, invading the land more and more. Accordingly the work of the waves was then more active and the assorting power greater. The marine organisms thrived, and locally there were even coral reefs and areas of oolite formation. Janensch thinks that the sauropods also waded around in these marine waters, but because the bottoms were sandy and therefore not sticky, as were the mud-flats of the dinosaur zones, they were not killed and their bones did not get into the shallow-water marine sandstones. The real reason for their absence seems to the present writer to be that shore-dwelling sauropods did not live in marine waters feeding on marine organisms, but rather that they were habituated to the fresh-water and

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[37] O. A. Peterson: A mounted skeleton of *Stenomylus hitchcocki*, etcetera. Ann. Carnegie Mus., vol. 7, 1911, p. 268.

[38] Op. cit., part ii, pp. 258-259.

[39] Op. cit., part ii, p. 247.

possibly the brackish-water marshes along the coast and rivers, feeding on aquatic land-derived plants.[40]

The present writer believes that the entombment of dinosaurs in the African Tendaguru clays and sands shows that the sauropods at least are found in their natural habitats, and that they were not killed "in troops" or through cataclysms. On the contrary they were wading around and feeding in the fresh- and brackish-water marshes, the areas of their burial, and into these marshes the rivers were unloading their sediments and the cadavers of the drowned reptiles—the armored dinosaurs, and the ornithopods that lived wholly on the higher and dry land. It seems probable that these aggrading areas along the ocean front were rather brackish- than fresh-water marshes, because of the great scarcity of theropod skeletons and pulmonate snails, and the complete absence of the fresh-water bivalves, the naiids. The presence of many armored dinosaurs and small ornithopods, all dismembered, with the bones in linear horizontal arrangement, is evidence in favor of river transportation into the areas of the marshes. We have here, then, reptiles associated which originally lived in different though closely approximated habitats.

CORRELATION OF THE TENDAGURU SERIES

Correlations by the Germans.—In Part II of the German publication, Hennig summarizes the various correlations made by previous geologists and paleontologists, and of these only one will be restated. The invertebrate fossils collected in 1907 by Professor Fraas have been studied by Krenkel.[41] His conclusions are that the great majority of the fossils are indicative of Neocomian or early Lower Cretaceous time, or more specifically, that the Mediterranean Valanginian, Hauterivian, and Barremian are represented. He adds that there may also be present in southern German East Africa strata of Cenomanian time, but that the fossils are not good enough to make this certain. On the other hand, nothing as to the presence of Jurassic was discerned.

According to Hennig,[42] the older workers with African fossils held that there is here a complete break between the Jurassic and Lower Cretaceous. The more recently collected marine faunas have, however, now established the fact that there is a complete transition from the Jurassic into the Lower Cretaceous, and this is also confirmed by the nature of the stratigraphic sequence.

[40] Op. cit., part ii, p. 260.

[41] E. Krenkel: Die untere Kreide von Deutsch-Ostafrika. Beitr. zur Pal. u. Geol. Œsterreich-Ungarns, vol. 23, 1910, pp. 201-250.

[42] Hennig: Op cit., part ii, pp. 3, 10.

"During the time from the oldest Dogger [= early Jurassic] to the end of the Lower Cretaceous, German East Africa was at no time completely out of the water." "The lowest deposits of the Tendaguru series, including the two lower dinosaur beds, belong in the Upper Jurassic."

As the *Trigonia schwarzi* zone is Neocomian, the Berlin authorities are agreed that the upper dinosaur zone is also Lower Cretaceous—a conclusion that need not necessarily follow.

Correlations on basis of dinosaurs.—Janensch[43] states that the African two upper dinosaur faunas show remarkable similarity with the Morrison fauna. This is seen in that in both regions the Sauropoda are of first importance, and with these are associated armored dinosaurs (but not stegosaurians), small to medium-sized Ornithopoda, and small mammals. There is, however, a greater variety in America, and, the present writer will add, a complete absence of all marine evidence, while there are present many fresh-water and pulmonate shells. The generic relationships of the dinosaurs, Janensch states, can not yet be indicated, though it seems that *Brachiosaurus* occurs in both areas. The Wealden dinosaurs, of presumably later or younger age, are far less closely related, so that the faunal kinship is decidedly with the United States. The Morrison, he believes, is, in any event, "transitional from the Jurassic to the Lower Cretaceous, and in this agrees very closely with the African saurian beds." This is, however, an assumption that needs confirmation, though the same statement has also been made by American vertebratists.

In tabular form Janensch's correlations are as follows:

Lower Cretaceous Aptian		Makonde series. Marine north of Tendaguru area	
Tendaguru Series	Lower Cretaceous Neocomian	*Trigonia schwarzi* marine sandstones Upper dinosaur friable limy-sandy shale (Wealden)	
	Upper Jurassic Malm	*Trigonia smeei* marine sandstone (Upper Kimmeridge-Tithonian)	
		Middle dinosaur friable limy-sandy shale (Kimmeridge)	
		Nerinea marine sandstone	Exact age not yet established (II, page 237)
		Lower dinosaur friable sandy marl	
		Granite and gneiss	

43 Janensch: Op. cit., part ii, pp. 84-85.

Correlations on basis of marine invertebrates.—A careful reading of these most interesting memoirs makes it evident that all of the workers are finally dependent in their correlations on the evidence presented by the ammonites. These are determined by Zwierzycki,[44] who regards those of the *Trigonia schwarzi* zone as a typical Mediterranean lower and middle Neocomian assemblage. The majority of the forms in other regions, he states, are at home in the upper Valanginian and in the Hauterivian. Only the forms of *Crioceras* and *Hamulina* may be indicative of a higher zone, the Barremian. He also distinctly points out that the forms occurring in Europe are there restricted to distinct horizons, but that in the Tendaguru region they are apparently associated.

The *Trigonia smeei* zone Zwierzycki also regards as having a mixed fauna, with nine species that elsewhere again hold two horizons. *Haploceras elimatum* ranges from the upper Kimmeridge into the Tithonian, while *Phylloceras silesiacum* is restricted to the Tithonian (Stromberg). *Perisphinctes bleicheri* is also indicative of Tithonian. *Haploceras kobelli* is of upper Kimmeridge age. From this evidence the author concludes that the *T. smeei* zone is of about the time of the upper Kimmeridge and Tithonian, or, in other words, at the top of the Jurassic. (See Buckman's views beyond.) In this connection it should not be forgotten that above the Kimmeridge follows the Portlandian and Purbeckian (at least 1,000 feet thick in England and thicker on the continent), and, further, that the position of the Tithonian has long been under discussion, and even though the majority of stratigraphers refer it to the Jurassic, others regard it as of Lower Cretaceous time. Kayser states that about a dozen of its species pass upward, and that the succession of its ammonite beds leads imperceptibly into the Lower Cretaceous. Therefore the Tithonian species of the *T. smeei* zone may have been actually living in Lower Cretaceous time.

The Nerinea zone, Zwierzycki states, is difficult to correlate on the basis of cephalopods alone, because of the six species present the only guide is *Perisphinctes sparsiplicatus,* a form from the Katrol formation of India. He adds that if this species, founded on a single specimen, is from the lower Katrol, it may mean that the age is Oxford, and if upper Katrol, then the time is Kimmeridge. Because the Nerinea zone underlies the middle dinosaur beds, he is inclined to refer the former to the Oxfordian. However, he is not certain about this, and adds, "At least it is older than Upper Kimmeridge." Accordingly he regards the middle dinosaur zone

[44] J. Zwierzycki: Wissenschaftliche Ergebnisse, etcetera, part III, pp. 83-87.

as Lower Kimmeridge, and the lower dinosaur beds as lowest Oxford or even Kelloway.

Dietrich[45] has studied all the gastropods of the Tendaguru series and has named thirty-six species, either specifically or generically, of which only seven were previously known forms. On the basis of these fossils he concludes that the *Trigonia schwarzi* zone indicates Tithonian to middle Neocomian, the *T. smeei* zone equals Kimmeridgian, and the Nerinea zone equals middle Dogger to Kimmeridgian.

> "The gastropods of the Tendaguru series from the base up to the upper dinosaur zone give one a fairly clear impression that it is a shallow-water assemblage of Kimmeridgian age, and that it is independent of the higher faunas that are of Lower Cretaceous time. In regard to the age of the Nerinea and basal beds the correlation is uncertain."

Lange,[46] on the basis of the bivalves, makes the following correlation:

Zone with *Trigonia schwartzi, T. transitoria*, and *T. conocardiiformis* = Middle Neocomian.
Upper dinosaur zone = Lower Neocomian.
Zone with *Trigonia smeei* and *T. ventricosa* = Uppermost Jurassic.

Conclusions by Buckman.—As the geologic age of the Tendaguru series is largely based on the inherent evidence of the ammonites, the writer asked his friend, Dr. S. S. Buckman, the English authority on Middle Mesozoic ammonites and stratigraphy, to read the work of Zwierzycki with a view of endorsing or emending his age determinations and correlations. This Buckman has done, and, as will be seen from his statements, there is no essential disagreement. Under date of November 8, 1916, Doctor Buckman writes me as follows:

> "With regard to the Tendaguru series there seems no reason to take exception to Zwierzycki's general conclusion—that the series ranges in date from Jurassic to Neocomian. The *Trigonia schwarzi* beds are Neocomian, the *T. smeei* beds are Jurassic. He says that the Ammonites of the latter indicate a mixed fauna; the highest, *Craspedites*, would indicate Purbeckian—infra-Neocomian at any rate: some others are Kimmeridgian forms, as he points out: to these may I think be added his *P. bleicheri*, of which the identification seems doubtful—it has greater likeness to one of our Upper Kimmeridgian species: the author cites it as evidence for Portlandian.
>
> "In the Nerinea beds *P. sparsiplicatus*, of which the identification is much to be questioned, suggests more nearly another of our Upper Kimmeridge forms, while *P.* cf. *achilles* would be about border-line of Kimmeridgian-Argovian.
>
> "The Tendaguru series thus appears to be a straddle formation from the

[45] W. O. Dietrich: Op. cit., part iii, pp. 109-110.
[46] E. Lange: Op. cit., part iii, p. 289.

Jurassic to the Neocomian, with the *T. smeei* beds a straddle formation from Kimmeridgian to Purbeckian; and I make no objection. . . .

"The Tendaguru series, it seems to me, began about the time of the Sundance, and, with perhaps several invisible stratigraphical gaps—non-sequences we call them here—bridged the break between Sundance and Morrison, finishing off in Neocomian times."

In a later letter (February 6, 1917) Buckman adds:

"I do not see why the upper dinosaur clay is placed in the Neocomian. Why should not this be associated with the *T. smeei* zone, and the break between Jurassic and Cretaceous be placed above it? What is the reason for not taking such an obvious course?"

Conclusions by Schuchert.—From the preceding synopsis of the work of the German paleontologists and of Buckman, it is seen that all are agreed that the *Trigonia schwarzi* marine zone, a sandstone of about 16 feet in thickness, is of Neocomian (lower to middle) or Lower Cretaceous time. Some of the forms, however, are indicative of as high a stage as the Barremian, and this means that this fauna is a mixed assemblage, of which some species, in the Mediterranean countries, lived only during a limited part of the time, either during the middle or the lower part of the Lower Cretaceous.

Beneath the *Trigonia schwarzi* zone lies the upper dinosaur horizon, of 130 feet thickness, composed of sandy shales and sandstones. This is referred by the Germans to the base of the Lower Cretaceous, mainly because it appears to them that the Tendaguru is a continuous series of deposits, and further because the next older marine *T. smeei* zone is of the Upper Jurassic (Kimmeridge and Tithonian).

We are told that there is no striking difference between the saurians of the upper and middle dinosaur zones, while there is a total dissimilarity in the lower one. In other words, the same genera and in some cases even the same species of dinosaurs, it would appear, lived in Jurassic and Lower Cretaceous times, while the marine faunas changed considerably in the same time.

The dinosaur distribution is as follows:

Gigantosaurus africanus	Upper dinosaur zone.
Gigantosaurus robustus	Upper dinosaur zone.
Brachiosaurus brancai	Upper and middle dinosaur zones.
Brachiosaurus fraasi	Upper and middle dinosaur zones.
Dicræosaurus sattleri	Upper dinosaur zone.
Dicræosaurus hansemanni	Middle dinosaur zone.
Kentrosaurus æthiopicus	Upper and middle dinosaur zones.
Omosaurus (?)	Upper and middle dinosaur zones.
Polacanthus (?)	Upper dinosaur zone.

We have long been holding that land vertebrates, living under more variable conditions, change far more quickly than do the marine invertebrates of long-enduring equable environments, and yet in the present case hardly any of the species of the *Trigonia smeei* beds continue into the time of *T. schwarzi*. There are only five marine bivalves known to bridge this time, a class of long-lived animals and as such having the least value as zonal markers; yet *Brachiosaurus brancai, B. fraasi,* and the genera *Dicræosaurus* and *Kentrosaurus* lived longer, across the time from Jurassic into Lower Cretaceous. If the dinosaurs are correctly determined, then all of the invertebrates of the *T. smeei* zone should be reinvestigated to see if some of them can not be referred to the Lower Cretaceous and so brought into harmony with the evidence of the dinosaurs, or the latter seemingly must be shown to be dissimilar in the two upper horizons. Under these circumstances, it appears best, at least for the present, to follow the suggestion of Buckman, who regards the middle and upper dinosaur zones as of Upper Jurassic age. This does not necessarily mean that there is a time break between the upper dinosaur and the *T. schwarzi* zones, though the present writer is inclined to look on the available evidence as indicating a hiatus here between the Jurassic and the Lower Cretaceous.

On the other hand, it is plain that the faunas of the upper marine horizons and the two upper dinosaur zones are more closely related to one another than they are to those of the Nerinea and lower dinosaur horizons. The writer therefore raises the further question whether the Tendaguru is actually a continuous series of deposits or is again broken at the top of the Nerinea zone? The fauna of the Nerinea beds is a small one, with forms that have little stratigraphic value, and this nearly all of the paleontologists concerned with the work have noticed. As for the dinosaur evidence in the lowermost zone, it is as yet unknown other than that they are all small, and this is a very significant fact; all large sauropods appear to be absent. The writer therefore thinks that the evidence as it now stands indicates rather that the lower dinosaur zone and the Nerinea beds are of earlier Jurassic time, followed by a break in the Tendaguru series. Then come the two higher marine and the two main dinosaur horizons that may be of continuous deposition and, if so, bridge over the time from the Jurassic into the Lower Cretaceous.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

MEGANOS GROUP, A NEWLY RECOGNIZED DIVISION IN THE EOCENE OF CALIFORNIA *

(*Read before the Paleontological Society January 2, 1918*)

BY BRUCE L. CLARK

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Introductory Statement

During the summer of 1917, while studying the Tertiary formations on the north side of Mount Diablo, in the Mount Diablo quadrangle, the writer noticed a marked difference in strike between certain of the beds which up to this time had been considered a part of the Tejon (Upper Eocene). This discordance, a difference of nearly 50 degrees, meant one of two things: either it was due to faulting or to an unconformity. Later

* Manuscript received by the Secretary of the Geological Society March 5, 1918.

detailed work has shown conclusively that here we have an unconformity, which was the result of crustal movements of considerable magnitude.

Briefly stated, it is the writer's conclusion, after studying the unconformity mentioned above, together with fairly large collections of fossil invertebrates from both above and below the line of contact, that we have here the evidence of a structural break of more than local importance; that the fauna found above the unconformity in beds associated with the coal strata is typically Tejon in aspect, while the fauna found below is very different from that of the Tejon and comes from beds which apparently belong to a distinct epoch of deposition, which has not previously been recognized as such. Thus, formerly only two divisions of the Eocene have been recognized in the region of Mount Diablo, the Martinez (Lower Eocene) and the Tejon (Upper Eocene). The new division, described in this paper, is a part of a series of beds which in this vicinity had previously been considered as being of Tejon age. It is the writer's belief that beds belonging to this epoch of deposition are fairly widespread throughout the State. In some localities in California they have been referred to the Tejon, in others to the Martinez. The beds of the newly recognized epoch of deposition are designated in this paper as the Meganos Group.

Previous Literature concerning the Eocene of the Mount Diablo Quadrangle

It is surprising how little detailed work has been done on the Eocene of the Mount Diablo quadrangle. Only a brief statement concerning this portion of the section in this area was given in the early report of the Geological Survey[1] of California. The invertebrate fauna obtained from beds above the coal, which is found in the vicinity of the old mining towns of Nortonville, Sommerville, and Stewartville, was referred to the Tejon formation. This division was regarded at that time as a part of the Upper Cretaceous (Cretaceous B). A few species were also found in strata below the coal and were referred by Gabb, the paleontologist of the survey, to a horizon intermediate between his Cretaceous A and B—that is, the Martinez. Gabb[2] described a number of invertebrate species from the beds immediately above the coal strata of this section.

Turner,[3] in a paper entitled the "Geology of Mount Diablo, California," mentioned only very briefly the Eocene section of this area. He included all of the Eocene in the Tejon. Even up to this time (1891) the Eocene

[1] G. D. Whitney: Report of progress and synopsis of the field-work from 1860-1864. Geol. Surv. of California, vol. 1, 1865, pp. 23-32.

[2] W. M. Gabb: Paleontology of California, vols. 1 and 2, 1864-1869.

[3] T. W. Turner: Bull. Geol. Soc. Am., vol. 2, 1891, p. 395.

age of these deposits was still questioned by many geologists, and Whitney's original statement that here was a continuous and conformable series, extending from the center of the mountain mass out to the valley and including beds from Lower Cretaceous to uppermost Tertiary, remained unchallenged.

T. W. Stanton,[4] in 1896, made a special study of the Eocene beds of California in order to determine if possible their stratigraphic and faunal relationships to the Upper Cretaceous deposits of this general region. His work showed conclusively that there was a decided faunal break between these two horizons. Stanton at this time studied the Eocene section on the north side of Mount Diablo, and in his paper are given several lists of fossil invertebrates. With regard to the position of this fauna he states:[5] "The fauna represented by these lists is clearly the original Tejon fauna, that occurs in the neighborhood of Fort Tejon, New Idria, and elsewhere along the Coast Ranges of Washington. Its Eocene character has been recognized by Conrad, Marcou, Heilprin, White, and others."

R. E. Dickerson[6] has described in considerable detail the stratigraphy and fauna of the Martinez Group of this section. He described the unconformity between the Martinez and the Chico (Upper Cretaceous) and also an unconformity at the top of the Martinez, which he believed to be the contact between the Martinez and the Tejon. It will be shown in this paper that this latter unconformity is not between the Martinez and the Tejon, as he believed, but between the Martinez and a series of beds, here referred to as the Meganos Group, which are intermediate between the Martinez and Tejon, and separated also from the Tejon by an unconformity.

Meganos Group North of Mount Diablo

Stratigraphy and Lithology

The area under consideration.—The principal area under discussion is a strip extending from about one mile to the west of the old coal-mining town of Nortonville, east and a little to the south of the eastern edge of the Mount Diablo quadrangle. The outcrops, including the Martinez, Meganos, and Tejon groups, dip to the north, the angle of dip varying

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[4] T. W. Stanton: Faunal relation of the Eocene and Upper Cretaceous on the Pacific coast. Seventeenth Ann. Rept. U. S. Geol. Surv., pt. 1, 1896, pp. 1011-1059.

[5] Op. cit., p. 1021.

[6] R. E. Dickerson: The stratigraphic and faunal relations of the Martinez formation to the Chico and Tejon, north of Mount Diablo. Univ. of California Publ. Bull. Dept. Geol., vol. 6, no. 8, 1911, pp. 171-177; Fauna of the Martinez Eocene of California. Univ. of California Publ. Bull. Dept. Geol., vol. 8, no. 6, 1914, pp. 61-180.

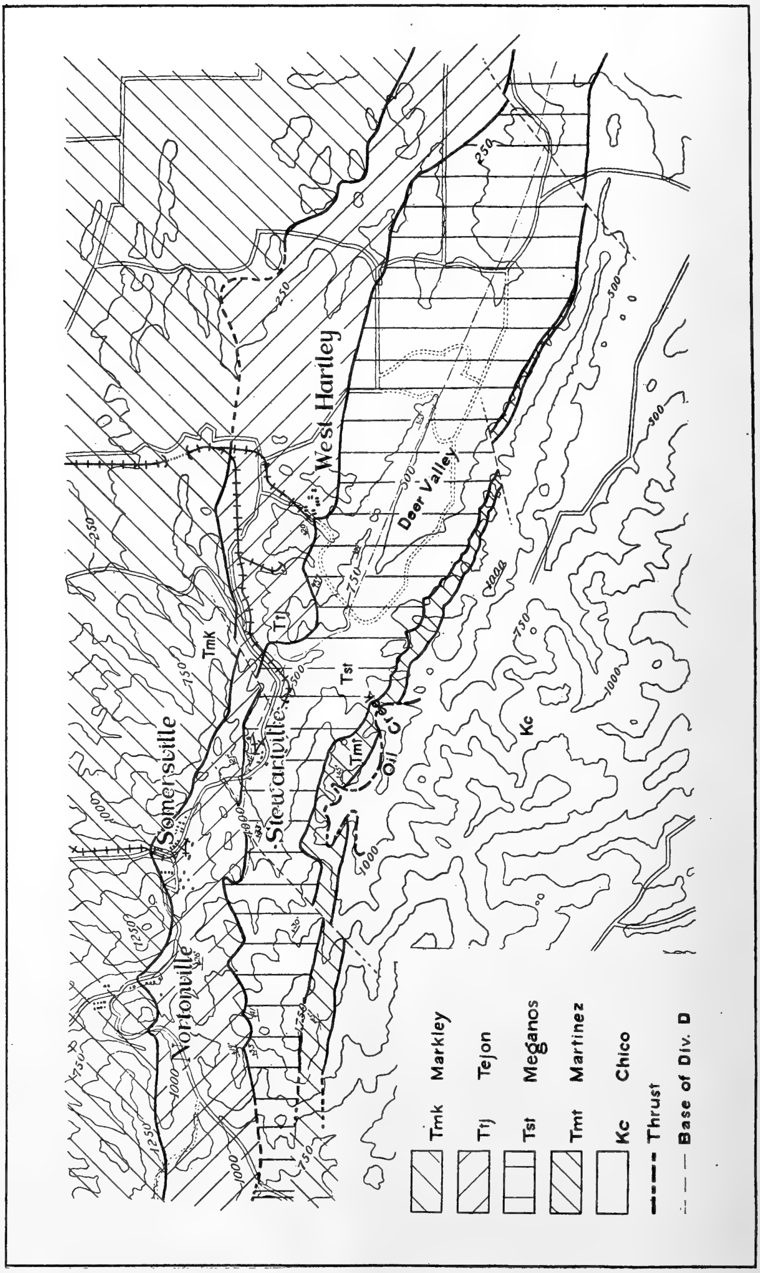

FIGURE 1.—*Areal Map of the Eocene Deposits to the north of Mount Diablo*

from 15 to 40 degrees. The greatest width of these outcrops is about two and a half miles.

The beds of the Meganos Group in this area rest unconformably on those of the Martinez Group. This unconformity, as stated above, was first described by R. E. Dickerson. The Lower Tejon, as recognized at that time, is the base of the Meganos, as described in this paper. The Meganos beds in this area have a maximum thickness of approximately

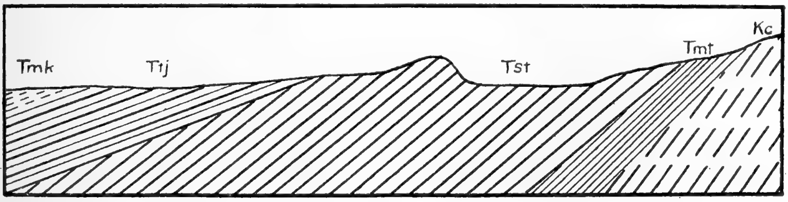

FIGURE 2.—*Cross-section showing the Eocene Groups as found on the north side of Mount Diablo*

Kc = Chico. Tmt = Martinez. Tst = Meganos. Ttj = Tejon. Tmk = Markley (Oligocene).

3,000 feet. The section may be roughtly divided into five lithologic members; these, beginning at the base, will be designated divisions A, B, C, D, E.

Summary of lithology of section.—The following is a generalized section of the Eocene groups as found on the north side of Mount Diablo. The Martinez portion of the section is copied from Dickerson's paper,[7] "Fauna of the Martinez Eocene, California."

		Feet
Tejon Group	6. Clay shales with minor amount of sandstone..	500
	5. Fine, buff-colored sandstone; in places hard, calcareous layers contain marine fossils.....	175
	4. Sandy shales; exposures poor; soil very red...	75
	3. Light gray to white, angular-grained sandstones, coarse to medium in texture; cross-bedding common, with minor layers of chocolate-colored shales; two important coal layers	75–400
	2. Chocolate-colored shales, ashy in places, with thin lenticular layers of coarse sandstone; coal layer locally known as Black Diamond vein	50
	1. Conglomerate	0–20

Unconformity

[7] R. E. Dickerson: Univ. of California Publ. Bull. Dept. Geol., vol. 8, no. 6. 1914, p. 71.

			Feet
Meganos Group	E.	Clay shales and sandstones at top, grades down into fine, massive, poorly indurated sandstone; exposures of the beds of this division are very poor	0–1,500
	D.	Sandstone of medium texture; thin-bedded near bottom; more massive at top; yellow brown to gray in color. The massive sandstones near top contain lenses of harder, calcareous and fossiliferous sandstones	0–300
	C.	5. Dark slate-gray shales; bedding planes fairly distinct; light calcareous nodules and lenses.	0–230
		4. Sandstone, fine to coarse in texture; in places forms a grit; contains thin clay lenses; in places contains considerable carbonaceous material	110
		3. Dark slate-gray shales, similar to (1) and (5).	90
		2. Sandstone, medium to fairly coarse; weathers on surface a rusty brown; grains chiefly of quartz and mica	50
		1. Dark slate-gray, clay-shale; bedding planes indistinct; carbonaceous material abundant...	75
	B.	Coarse to medium fine, quartzitic, gray to gray-brown sandstones, with some fine conglomeratic layers	700
	A.	Heavy conglomerates; boulders composed of quartzites, chert, limestone and large angular slabs of sandstone, containing typical Chico (Upper Cretaceous) fossils	50
Unconformity			
Martinez Group		5. Gray-green shale	300
		4. Gray-green, glauconitic sandstone; Trochocyathus zitteli beds	50
		3. Fine-grained, gray sandstone	200
		2. Shales and sandstones	100
		1. Brown conglomeratic sandstone; Meretrix dalli beds	50
Unconformity			
Chico.			

The conglomerates at the base of the Meganos Group, division A, because of their peculiar character, are worthy of mention. Here great angular slabs of fossiliferous Chico sandstone, sometimes 5 or 6 feet in

length, or even more, are found associated with the well rounded quartzitic and igneous boulders, and with these are found numerous smaller limestone and sandstone pebbles, which were derived either from the Martinez or the Chico, thus showing conclusively that these beds may be considered as a true basal conglomerate.

The shales of division C of the Meganos are especially noticeable in that they are so different from anything found in the Tejon on either the north or south side of Mount Diablo. The dark color, calcareous lenses and nodules, mode of slaking on the surface into small fragments, presence of carbonaceous material and layers of coarse sandstone which separate the different shale members are all very similar to lithological characters of the Knoxville shales (Lower Cretaceous or Upper Jurassic), as seen in certain sections of this general area. These sediments probably represent shallow-water conditions of deposition, and were perhaps laid down in land-locked or partially land-locked basins.

In the basal chocolate-colored shales of the Tejon great quantities of impressions of leaves, rushes, and fossil wood are found. These beds, which may be traced for many miles to the east and beyond the eastern boundary of the quadrangle, contain everywhere the leaf impressions in abundance. They will undoubtedly yield a large and well preserved flora for the paleobotanists who wish to study them in the future. These leaf shales were apparently laid down in marginal marine swamps. The presence of shells, belonging to the genus Corbicula, in a layer of standstone in the shales testifies as to the brackish or fresh-water conditions during deposition.

The most important of the coal beds of this region, and one which was mined throughout most of the area, is found near the top of these lower Tejon shales. In the vicinity of Nortonville this bed is known as the "Black Diamond Vein." It is reported to have a maximum thickness of about 4 feet. Above this coal layer at Nortonville is a sandy, conglomeratic bed varying from 1 to 3 feet in thickness, which is very highly impregnated with iron, so much so in places that it may be called an iron ore. Rush and leaf impressions were found also in this layer. The close association of this bed with the leaf shales and coal, together with the fact that the iron deposit is limited to a definite layer over a considerable area, suggests a primary rather than a secondary origin.

The coarse, cross-bedded, light-colored sandstones immediately above the shale may well have been deposited under somewhat similar conditions. Two of the important coal-layers, the "Little" and "Clark" veins, mined for many years at Nortonville and Somerville, are found in these sandstones. The coal of the Clark vein, which is about 2½ to 3 feet in

thickness as exposed in the mine at Nortonville, is found intercalated between the coarse, white, quartzitic sands without a trace of shale.

Evidence for unconformity between Meganos and Tejon.—The most important evidence for unconformity between the Meganos and the Tejon is the great difference in strike between the beds of the two horizons, seen at numerous localities; this is very noticeable at the coal mine at Stewartville, where the difference approximates 50 degrees. The basal sandstone of division D is here in contact with the Tejon, the thickness of the standstone being approximately only 150 feet. When followed to the west of Stewartville, the sandstone soon disappears and the basal beds of the Tejon rest directly on the upper dark-colored shale (division C), and a little to the west and south of Nortonville the Tejon rests on the first sandstone member from the top of division C. To the southeast of Stewartville the sandstone of division D emerges from under the Tejon very rapidly, forming the ridge north of Deer Valley; the shaly sandstones and shales of division E also appear, and within 3 or 4 miles of Stewartville they show their maximum thickness of 1,500 feet. In the canyon to the south of the Star mine, a distance of not much more than a mile from Stewartville, these upper shales of division E are well developed.

In going to the southeast, besides this difference in strike and the rapid emergence of the upper Meganos beds from beneath the Tejon, a marked difference in dip was obtained at a number of localities. In general it appears that there is a difference in dip between the two horizons throughout the entire length of the area. At the west end of the area southwest of Nortonville there is a maximum difference in dip of 18 degrees between the Upper Meganos beds and those of the Lower Tejon. In the vicinity of Stewartville the difference approximates only about 5 degrees, while in the vicinity of West Hartley the difference is between 15 and 20 degrees.

In the western part of the area under discussion, heavy conglomerates are found at the base of the Tejon. In some places the conglomerate has a thickness approximating 20 feet. To the east, in the vicinity of Stewartville and West Hartley, the conglomerate disappears and the chocolate shales at the base of the Tejon rest on the shales and shaly sandstones of division E of the Stewartville, making it impossible to find a sharp contact anywhere. As has been already stated, in the western part of the area the basal Tejon conglomerate rests on the dark shale of division C, and at a number of localities a sharp contact was located. This contact is decidedly irregular, and the bedding planes of the shale are cut off and butt into the conglomerate. It is a noticeable fact, also, that there is considerable carbonaceous material at the contact.

FAUNAL LIST

The following is a preliminary list of the Meganos species obtained from the section described above. The majority of these came from one horizon, the sandstones of division D; a few species were found in the fine sandstones of division E:

Pelecypoda:
- *Acila gabbiana* Dickerson.
- *Antigona*, n. sp.
- *Avicula*, n. sp.
- *Cardium marysvillensis* Dickerson.
- *Cardium brewerii* Gabb, n. subsp.
- *Corbula*, n. sp.
- *Crassatellites grandis* (Gabb), n. subsp.
- *Crassatellites*, n. sp.
- *Crassatellites*, n. sp.
- *Dosinia*, n. sp.
- *Diplodonta*, n. sp.
- *Ficopsis*, n. sp.
- *Glycimeris*, n. sp.
- *Leda gabbi* Conrad, n. subsp.?
- *Leda*, n. sp.
- *Leda* sp.
- *Marcia (?) conradi* Dickerson.
- *Meretrix? dalli* Dickerson.
- *Meretrix?* cf. *ovalis* Gabb.
- *Meretrix?* n. sp.
- *Macrocallista*, n. sp. aff. *M. conradi* (Gabb).
- *Modiolus ornatus* Gabb.
- *Ostrea* sp.
- *Phacoides*, n. sp.
- *Pholas?* sp.
- *Psammobia*, n. sp.
- *Solemya*, n. sp.
- *Solen stantoni* Weaver.
- *Spisula merriami* Packard.
- *Tellina*, n. sp., sp. A.
- *Tellina*, n. sp., sp. B.
- *Tellina*, n. sp., sp. C.
- *Tellina* sp.
- *Venericardia planicosta* cf. var. *hornii* Gabb.

Gastropoda:
- *Actæon*, n. sp.
- *Aplustrum?* n. sp.
- *Architectonica*, n. sp., sp. A.
- *Architectonica*, n. sp., sp. B.
- *Brachyspingus?* n. sp.
- *Chrysodomus*, n. sp.
- *Chrysodomus*, n. sp.
- *Fusinus*, n. sp.
- *Galleodea*, n. sp.
- *Galleodea sutterensis* Dickerson.
- *Haminea*, n. sp.
- *Natica gesteri* Dickerson.
- *Natica hornii* Gabb.
- *Neptunea*, n. sp.
- *Oliva*, n. sp.
- *Pseudoliva*, n. sp.
- *Siphonalia?* sp.
- *Surcula*, n. sp.
- *Scaphander*, n. sp.
- *Turris*, n. sp., sp. A.
- *Turris*, n. sp., sp. B.
- *Turris*, n. sp., sp. C.
- *Turritella reversa* Waring.
- *Turritella merriami* Dickerson, n. var.
- *Turritella* n. sp.

Scaphoda:
- *Dentalium cooperii* Gabb.

Cephalopoda:
- A Nautiloid, genus indt.

Anthozoa:
- *Turbinolia* sp.
- *Flabellum*, n. sp.

Echinodermata:
- *Schizaster leconteii.*

COMPARISON OF MEGANOS AND TEJON FAUNAS

At the present time 68 described species of invertebrates are known from the Tejon beds on the north side of Mount Diablo; most of these

were listed either by Stanton or Dickerson in the papers already referred to. This upper fauna, referred by Dickerson to his Balaniphyllia zone, contains many of the species which are so typical of the type section of the Tejon, such as *Meretrix hornii* Gabb, *Meretrix tejonensis* Dickerson, *Conus remondii* Gabb, *Ficopsis* cf. *cowlitzensis* Weaver, *Turritella uvasana* Conrad, *Turritella uvasana bicarnata* Dickerson.

The fauna of the Meganos, as obtained from the section described above, is very different from that of the Tejon. Sixty-five species, listed above, have been recognized in this fauna; of these, 4, possibly 6, are found in the Tejon beds immediately above; 2 or 3 more are found in the Tejon of other sections. It is interesting to note that over half of the Meganos species are new; also that a number of these forms are found in beds in the southern part of the State, which have been referred to as being Martinez in age. Reference will be made to this occurrence further on in the paper.

It is the writer's conclusion, after comparing this fauna from the Meganos beds with that of the Tejon, that here is good evidence which points to a marked faunal as well as stratigraphic break between these two horizons.

Meganos Group to South and West of Mount Diablo

GENERAL STATEMENT

A study of the Eocene section on the south and west sides of Mount Diablo has shown that here also the Meganos beds are present and lie unconformably below the Tejon. One of the best known sections of the Eocene of the Mount Diablo region is found on the south and west sides of the mountain, the maximum thickness in this area being about 2,500 feet. These beds are described in a recent publication by Dr. R. E. Dickerson.[8] Here he established three faunal zones, all of which he referred to the Tejon. The lowest zone he called the Turbinolia zone; the fauna from near the middle of the section he referred to his Rimella simplex zone, while that found in the upper beds was referred to his Balanophyllia variabilis zone.

The writer's conclusions, after studying the fauna from the south and west side of Mount Diablo, is that the beds containing the faunas designated by Dickerson as the Turbinolia and Rimella simplex zones are not

[8] R. E. Dickerson: Note on the faunal zones of the Tejon Group. Univ. of California Publ. Bull. Dept. Geol., vol. 8, no. 2, 1914, pp. 17-25; Stratigraphy and fauna of the Tejon Eocene of California. Univ. of California Publ. Bull. Dept. Geol., vol. 9, no. 17, 1916, pp. 363-524.

Tejon, but belong to the Meganos period of deposition; that neither are to be correlated with the typical Tejon of the type section. The first true Tejon in this section is represented by the beds of Dickerson's Balanophyllia zone. In this section as well as on the north side of the mountain these latter beds, the true Tejon, are found unconformable on top of the Meganos.

Near the western edge of the Mount Diablo quadrangle, beds belonging to the Meganos Group are found unconformably beneath beds containing the "Balanophyllia fauna." These outcrops are found on the north side of the ridge north of Pine Canyon, extending to the west onto the Concord quadrangle. Not as much detailed work has been done by the writer on the Meganos portion of the section in this area to the west of Mount Diablo as has been done on the section in the area to the north of the mountain; for this reason only a very general statement as to the lithology and fauna of this section can be made.

STRATIGRAPHY AND LITHOLOGY

The basal conglomerate of the Meganos in this western area is found on the ridge to the south and west of the mouth of the Arroya del Cerra. Here the conglomerate rests on dark shales and carbonaceous brown sandstones, which very probably are of Cretaceous age. The conglomerate has a maximum thickness of close to 20 feet. The lower portion of the conglomerate is fairly coarse, the pebbles being composed largely of shale, limestone, sandstone, and conglomeratic sandstone, together with some quartzitic and igneous boulders. Some of the boulders of sandstone are angular and are as much as a foot to a foot and a half in length. Typical Chico fossils were found in some of the conglomeratic sandstone boulders. The pebbles in the upper beds of this conglomerate consist chiefly of fine angular fragments of shale, derived apparently from the dark shales immediately below.

Above the basal conglomerate, just described, is, roughly estimated, 150 to 200 feet of medium fine, yellow-brown, fossiliferous sandstone, and above this about 1,800 feet of dark-colored shales, fine sandstone, and shaly sandstone.

The line of division between the Meganos and Tejon is marked by a narrow band, possibly two feet thick, of fine conglomerate. The pebbles at the base consist of quartz, black chert and red chert similar to the cherts of the Franciscan, and shale. Above this the pebbles consist almost entirely of angular fragments of shale in a matrix of coarse, light gray sandstone. Thus here again we apparently have a true basal conglomerate.

The Meganos beds of this section have a strike of approximately north 40° west, while those of the Tejon have a general strike of about north 70° west. Thus, in following the Meganos beds to the southeast they are rapidly overlapped by those of the Tejon, disappearing entirely within a short distance.

FAUNA

Up to the present time only a comparatively small fauna has been obtained from the Meganos of this section. More detailed work will undoubtedly yield a larger fauna. Some of the species found are:

Cardium brewerii Gabb, n. subsp.
Glycimeris sp.
Psammobia, n. sp.; also found on north side of Mount Diablo.
Macrocallista, n. sp.; also found on north side.
Meretrix, n. sp.; also on north side of mountain.
Amauropsis, n. sp.
Rimella n. sp.
Galleodea sutterensis Dickerson; also found on north side.
Mitra, n. sp.
Scaphander, n. sp.; also found on north side.
Venericardia, n. sp.?

Other Occurrences of Meganos

GENERAL REFERENCE

It is the writer's opinion that there are other localities in different parts of California where beds are found which apparently belong to the same general epoch of deposition as those of the Meganos. Two of the better known localities will be discussed here.

COALINGA DISTRICT

In the Eocene to the north of Coalinga there is a contact, which has been discussed by several writers. The beds above this contact contains a typical Tejon fauna—a fauna which contains a considerable number of the highly ornamented molluscan species found in the Lower Tejon of the Mount Diablo region and in the type section at the south end of the San Joaquin Valley. One of the most common species found in the beds below this contact is *Turritella andersoni* Dickerson. This species is so abundant in these beds in this general area that they will be referred to as the Turritella andersoni beds. In 1912 J. A. Taff[9] described an unconformity between the Turritella andersoni beds and the lower sandstones

[9] J. A. Taff: Pal. Soc. Am., 1912, p. 127.

of the Tejon, locally known as the Domengine sands. He suggested that the Turritella andersoni beds might be Martinez in age. E. T. Dumble[10] was so impressed with the importance of this contact that he unhesitatingly expressed the belief that the Turritella andersoni beds were Martinez in age. In his paper entitled "Notes on Tertiary deposits near Coalinga oil field and their stratigraphic relations with the Upper Cretaceous" occurs the following statement:

"Our work now proves that this lower member of the Eocene (the Martinez) is of very considerable extent southward on the west side of San Joaquin Valley; that it consists of three or more clearly defined members, and that, in addition to the unconformity already described between it and the Cretaceous, there also exists a decided unconformity between it and the overlying Tejon."

Robert Anderson and Robert W. Pack,[11] in their paper entitled "Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, California," referred the Turritella andersoni beds to the Martinez? Their point of view is stated as follows:

"The relation of the Martinez? formation to the overlying Tejon formation may be stated with more assurance[12] to be one of unconformity. . . . The writers believe that the beds here described as Martinez? are probably the equivalent partly of the Martinez and partly of the Tejon, and that the unconformity here registered in the Eocene is not to be correlated with that between the Martinez and Tejon formations in the Mount Diablo region."

Thus in the foregoing we have the suggestion that possibly the Turritella andersoni beds are transitional between true Tejon and true Martinez.

Dickerson,[13] in his paper entitled "Stratigraphy and fauna of the Tejon Eocene of California," states his belief that the unconformity between the Turritella andersoni beds and the beds regarded as the base of the Tejon by the writers just quoted is not important. He says:

"Several workers in this field report a well marked unconformity in the middle of the section. The time represented by this unconformity is difficult to evaluate. The only method at present available is the faunal one, and, as has been previously shown, the faunas from above and below the unconformity are as a whole quite similar. There is no well marked difference in dip and strike reported along the unconformable contact; but the evidence consists of a sharp change in lithology and the penetration of the underlying strata by

[10] E. T. Dumble: Jour. of Geology, vol. 20, 1912, pp. 28-37.

[11] Robert Anderson and Robert W. Pack: U. S. Geol. Survey, Bull. no. 603, 1915, p. 66.

[12] More assurance than the unconformity between the Chico and the Martinez, just described in the paragraph preceding this.

[13] R. E. Dickerson: Univ. of California Publ. Bull. Dept. Geol., vol. 9, no. 17, 1916, pp. 428-429.

Cretaceous bore holes which are filled with sands of the overlying stratum. The unconformity reported is at least not of the same order as the unconformity between the Tejon and Martinez, as the structural and faunal break between these two groups is a great one. A very large number of Martinez species failed to bridge the gap. Such is not the case in the vicinity of Domangine Creek. The writer believes that the time break represented by this unconformity is at most of secondary order—that is, such as might separate two formations in a group."

After studying the fauna from the Turritella andersoni beds, the same material on which Dickerson based his conclusions, the writer was impressed with the fact that there are, in this fauna, so few typical Tejon species. He does not agree with a number of the specific determinations that Dickerson made, as given in his list from locality 1817. Evidently Dickerson did not consider the possibility of there being a third group coming in between the Martinez and the Tejon, and that if this were so one might well expect to find a larger number of species bridging the gap between this intermediate horizon and the Tejon than the gap between the Martinez and the Tejon. While the paleontological evidence for the correlation of the Turritella andersoni beds with the Meganos epoch of deposition may possibly not be the best at the present time, yet the stratigraphic evidence, together with the difference between the fauna of the Turritella andersoni beds and that of the Tejon above, makes it highly probable that here we are dealing with the same epoch of deposition as that to which the Meganos beds belong.

EOCENE OF CALABASIS QUADRANGLE, VENTURA COUNTY

C. A. Waring,[14] in a recent publication, has described the Eocene of the Calabasis quadrangle. Waring has divided this series in this area into the Martinez and the Tejon. It is stated that apparently the Martinez in this area grades up into the Tejon, the division between the two being entirely based on paleontological evidence. The fauna from these so-called Tejon beds, as he has listed and illustrated it, undoubtably belongs to the same epoch of deposition as the Turritella andersoni beds to the north of Coalinga.

It is interesting to note that several of the species in the so-called Tejon fauna, listed and figured by Waring, are apparently identical with certain of the new species or new subspecies in the Meganos beds of the Mount Diablo region. This is also true of several of the so-called Martinez species. One of the most striking examples is the fact that one of Waring's

[14] C. A. Waring: Stratigraphic and faunal relations of the Martinez to the Chico and Tejon of southern California. Proc. California Acad. Sci., 4th ser., vol. vii, no. 4, 1917, pp. 41-124, pls. 7-16.

new species of Turritella in his so-called Martinez, *Turritella reversa,* is found very abundantly in the Meganos beds of the Mount Diablo region.

NOTE.—During the summer of 1918 a number of the most important Eocene sections in southern California were studied by the writer; these included the Coalinga section and that of the Calabasis quadrangle, both mentioned above. The details of this work will be published in the near future. Briefly stated, the results are as follows:

In the Coalinga section a marked unconformity was found separating the Turritella andersoni beds (now known to belong to the Meganos epoch of deposition) from those of the typical Tejon. Not only is the contact irregular between the beds of these two groups, but also there is a noticeable difference in dip and strike at many localities, together with a true basal conglomerate at the base of the Tejon. In this general region the Martinez is absent; the Meganos group rests on the Upper Cretaceous shales.

In the Calabasis quadrangle, the section studied by C. A. Waring, whose paper was referred to above, the Martinez, the Meganos (Turritella andersoni beds), and the Tejon are all present. The Tejon of this section rests unconformably on the Meganos, the unconformity being indicated by an irregular contact, a marked difference in strike, and a possible difference in dip, together with a basal conglomerate. A very good typical Tejon fauna was obtained above this contact.

The writer's conclusion is that the Meganos group is to be correlated, at least in part, with the marine phase of the Ione as found at Table Mountain, near Oroville, California, the fauna from which latter beds has been referred by Dickerson[15] to his Siphonalis sutterensis zone. The writer has refrained from using the name Ione for the beds belonging to this epoch of deposition as found in different parts of California, for it is believed that the Ione very probably is composed of beds belonging to more than one epoch of deposition.

SUMMARY OF CONCLUSIONS

1. Mapping of the sedimentary series of the Eocene in the Mount Diablo quadrangle shows that there are three distinct stratigraphic units in these deposits instead of two, as was formerly recognized.
2. The beds of this newly discovered epoch of deposition come between the Martinez (Lower Eocene) and the Tejon (Upper Eocene).
3. The name Meganos has been given to this group of deposits.

[15] R. E. Dickerson: Note on the faunal zones of the Tejon group. Univ. of California Publ. Bull. Dept. Geol., vol. 18, no. 2, 1914, p. 23.

4. The Meganos beds have a maximum thickness of close to 3,000 feet and lie unconformably below beds of typical Tejon age and unconformably above beds of typical Martinez age.

5. Both of the unconformities, the one found at the top, the other at the base of the Meganos, are indicated by a difference in dip and strike, as well as by the presence of true basal conglomerates, together with other evidences of erosion.

6. It is believed that the Meganos epoch of deposition has a fairly wide distribution throughout the State; in some localities it has been included with the Martinez, in others with both the Tejon and the Martinez.

7. It is believed that the beds of the Meganos group are to be correlated, at least in part, with the marine beds of the Ione found at Table Mountain, near Oroville, California.

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MARINE OLIGOCENE OF THE WEST COAST OF NORTH AMERICA *

BY BRUCE L. CLARK AND RALPH ARNOLD

(*Read before the Paleontological Society January 2, 1918*)

CONTENTS

INTRODUCTORY REMARKS

This paper comprises a general survey of the known data concerning the paleogeography, climatic conditions, and faunal relationships of the Oligocene as found in California, Oregon, Washington, and Vancouver Island.

The great thickness of the marine Tertiary sediments on the West Coast forms a striking contrast to the much thinner deposits of the same age found in the Gulf and Atlantic Coastal Plain province; also the evidences of crustal movements of enormous magnitude, which are represented by great angular unconformities at various horizons in the Tertiary of the West Coast, indicate conditions very different from those which existed during the same general period in the eastern region. The

* Manuscript received by the Secretary of the Society March 5, 1918.

Tertiary deposits on the West Coast were, for the most part, laid down in geosynclinal depressions which paralleled the axes of the present mountain ranges. In these slowly sinking troughs the sediments sometimes accumulated to enormous thickness before deposition was interrupted, and the Tertiary deposits in the Coast Ranges have a maximum thickness of over 40,000 feet, of which fully 10,000 feet belong to that portion of the section here referred to the Oligocene. The position of the axes of these troughs varied during the different epochs of deposition, as did also the areas covered by the different seas. Therefore on the West Coast we find the conditions of deposition during the Tertiary paralleling very closely those which existed in the Appalachian province during the Paleozoic. One of the noteworthy differences between the Appalachian province and the Coast Range province is that in the latter the geosynclinal condition of deposition is still in operation, as seen in the Great Valley of California, where several thousand feet of Pleistocene and recent deposits have accumulated and deposition still continues, while the deposition in the last Appalachian trough was discontinued many ages ago.

Up to the present time the problems of local sequence and correlation of Tertiary deposits on the West Coast have been the paramount ones, and as yet very little evidence has been produced to establish an exact correlation of the larger part of this section with the corresponding horizons of either the East Coast of America or with Europe. This is especially true of that portion of the section referred to the Oligocene. The problems of local sequence[1] and local correlation of the different Tertiary sections on the West Coast have not been simple ones, and there still remains much to be done before the stratigraphic and faunal divisions of these series will be adequately known.

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[1] The following table shows the general stratigraphic divisions of the West Coast marine Tertiary, as recognized by the writers:

Pliocene:
  Merced Group. Includes Jacalitos, Etchegoin, Fernando, Purissima, Empire, Montessano.

Upper Miocene:
  San Pablo Group. Includes Briones and Santa Margarita formations.

Middle and Lower Miocene:
  Monterey Group. Includes Temblor and Vaqueros.

Oligocene:
  San Lorenzo Group. Includes Sooke formation on Vancouver Island and Lincoln, Porter, and Blakeley horizons of Weaver.

Eocene:
  Tejon Group. Meganos Group. Martinez Group.

Oligocene in California

SAN LORENZO FORMATION

Until the year 1914 the only marine beds in California that had been definitely referred to the Oligocene were a limited area of outcrops in the Santa Cruz Mountains. The San Lorenzo formation of this area was described and named by Ralph Arnold[2] in 1906. At the time these deposits were first studied it was believed that they graded upward into the Vaqueros (Lower Miocene). Recent work by Bailey Willis[3] apparently shows that there is an unconformity between the San Lorenzo beds of the type section and those of the Lower Miocene.

When Arnold described the San Lorenzo formation, he stated that the reason for his belief in the Oligocene age of these beds was that the fauna appeared to have both Eocene and Miocene affinities; this, together with their stratigraphic position, would, he believed, be sufficient to place them in the Oligocene. Later work has only emphasized the Eocene and Miocene relationships of the San Lorenzo fauna, and thereby strengthened the belief in their Oligocene age.

Recent investigations[4] have shown that deposits of San Lorenzo age are

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[2] For the original definition of the San Lorenzo formation and its fauna, see Professional Paper U. S. Geological Survey, no. 47, 1906, pp. 16-17. For description of stratigraphy and lithology, see Folio U. S. Geological Survey, nos. 1-163, 1909, pp. 3-4. For description of San Lorenzo fauna, see Proc. U. S. National Museum, vol. 34, 1908, no. 1617, pp. 345-388, pl. 33.

[3] An unpublished paper read before the Le Conte Geological Society in October, 1917.

[4] B. L. Clark, in 1914, discovered an unconformity in the beds mapped as the Monterey Group. See "The occurrence of Oligocene in the Contra Costa hills of middle California," University of California Publ. Bull. Dept. Geol., vol. 9, no. 2, 1915, pp. 9-21. The fauna found below this unconformity proved to be that of the San Lorenzo, that from the beds above being typical Monterey.

Beds of San Lorenzo age are now known to extend from Mount Diablo to as far south as Ventura County. In the Coast Ranges, bordering the west side of the San Joaquin Valley, these deposits are composed chiefly of organic shales, locally known as the Kreyenhagen shales. The work of the U. S. Geological Survey has shown that the Kreyenhagen shales are separated by a marked unconformity from Monterey deposits (Lower Miocene) above. See Ralph Arnold and Robert Anderson: Geology and oil resources of the Coalinga district, Bull. U. S. Geol. Survey, no. 398, 1908, p. 80; Robert Anderson and Robert W. Pack: Geology and oil resources of the west border of the San Joaquin Valley, north of Coalinga, California, U. S. Geol. Survey, Bull. no. 60, 1915, pp. 74-80. Also in this field there is an unconformity between these Oligocene shales and the Tejon (Upper Eocene) deposits below. A typical San Lorenzo fauna has been obtained from the Kreyenhagen shales.

Beds of San Lorenzo age are found in the San Emigdio Mountains at the south end of the San Joaquin Valley. Here these deposits have a maximum thickness of close to 3,000 feet, consisting chiefly of dark clay-shales and sandstones. These deposits were studied by a party from the Paleontology Department of the University of California during the summer of 1917. The results of this work show that these San Lorenzo beds are here separated from those of typical Monterey by an unconformity; also that in this section there is an unconformity between the San Lorenzo beds and those of the Tejon

fairly widespread throughout the State of California, and that in general these deposits are separated from those of the Monterey by a stratigraphic break. A study of the known fauna of the San Lorenzo emphasizes the importance of this break.

PALEOGEOGRAPHY

While much remains to be done before all the details are known about the distribution of the San Lorenzo deposits in California, yet enough is now known to enable us to outline in a general way the original basin of deposition, for apparently in California there was only one general basin. This was a long geosynclinal trough extending from at least as far south as the San Emigdio Mountains, at the south end of the San Joaquin Valley, to the region of Mount Diablo and possibly for 200 miles or more farther north. The deepest part of this trough was along where is now the eastern edge of the Coast Ranges or along the western side of the present San Joaquin Valley. This is indicated by the organic shales found in this region. Over a large part of the western Coast Ranges the San Lorenzo deposits are apparently absent, and where present they are represented by shallow-water deposits, carbonaceous clay-shales, and sandstones.

This big mediterranean sea probably connected with the main ocean to the north in the region of the present Santa Cruz Mountains, in which area is the type locality of the San Lorenzo. Very probably there was a connection to the south; however, not enough detail is known about the distribution of these deposits to enable one to say definitely where such a connection might be. The outline map of California (figure 1) gives the probable outlines of the San Lorenzo sea. This will undoubtedly be considerably modified with future work.

STRATIGRAPHIC RELATIONSHIP TO UPPER EOCENE

The San Lorenzo deposits in California appear to show a closer relationship to those of the Tejon (Upper Eocene) than to deposits of the Monterey (Middle and Lower Miocene). The comparison of the distribution of the Tejon strata with those of the San Lorenzo in California shows that the areas covered by these two seas were very much the same,

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(Upper Eocene). It is probable that these deposits will be found to extend a considerable distance to the south of the San Emigdio Mountains into Ventura County.

San Lorenzo deposits are now known to exist in the western Coast Ranges of California. They are believed to be present in the Santa Lucia Mountains bordering the coast and along the Salinas Valley to the east of here. Very little study has been made of the San Lorenzo deposits in this western area. In all the mapping that has been done, these beds have been included with those of the Lower Miocene (Monterey).

and that usually where the San Lorenzo beds are absent, there the Tejon also is missing. This apparently closer stratigraphic relationship of the San Lorenzo to the Tejon than to the Monterey is borne out by the fact

FIGURE 1.—*Outline of Sea in San Lorenzo Time (Oligocene)*

that as yet no record of large crustal movements, as indicated by a marked difference in dip and strike, has been reported as coming between the Tejon and the San Lorenzo.

COMPARISON OF DISTRIBUTIONS OF OLIGOCENE AND LOWER MIOCENE

A comparison of the area occupied by the Lower Miocene Sea with that of the Oligocene Sea shows a remarkable difference. The axis of the geo-

synclinal trough of the Lower Miocene epoch of deposition, as shown by the distribution of the organic shales, was in the area of what is now the western Coast Ranges. It is to be noted that this Lower Miocene Sea extended much farther to the north and to the south than did that of the

FIGURE 2.—*Outline of Sea in Monterey Time (Lower and Middle Miocene)*

Oligocene, and apparently the Lower Miocene geosynclinal trough was also wider than that of the Oligocene; this was especially so in the northern part of the State.

These differences in the distribution of the Oligocene and Lower Miocene make it presumable that there must have been crustal movements of

considerable magnitude separating the two epochs of deposition. This assumption is borne out by the fact that we find, especially in the eastern Coast Ranges, evidences of a marked unconformity between the San Lorenzo and the Monterey. The Kreyenhagen shales, which are of San Lorenzo age, were here folded and the folds cut off before the deposition of the Monterey or Vaqueros sediments on their upturned edges. See note on the Kreyenhagen shales at bottom of page 299.

Distribution of Oligocene in Oregon and Washington [5]

The condition of deposition in Oregon and Washington during Oligocene time was similar to that which existed during the same period in California. These beds were deposited in geosynclinal depressions partially inclosed by land. It seems very probable that there was one large trough, which extended between the western front of the Cascades and the Olympics, connecting with the ocean to the north between a land-mass, a part of which is now Vancouver Island, and the area now including the Olympic Mountains, and to the south in the region of the Columbia River. The greatest amount of folding of the beds, which were deposited in this trough, has been in the region of Puget Sound, where is found the greatest thickness of Oligocene sediments—a thickness of over 10,000 feet.

Fauna and climatic Conditions of Oligocene

GENERAL OBSERVATIONS

The fauna of the West Coast marine Oligocene is as yet only partially described. At the present time more than 200 species are known from

[5] Our present knowledge of the stratigraphy and faunas of the Oligocene of Oregon, Washington, and Vancouver Island is due, to a large extent, to the work of Ralph Arnold, Harold Hannibal, and C. E. Weaver. It was largely through the field-work of Hannibal during the years of 1911 and 1912 that the stratigraphic sequence, now for the most part generally accepted, was first established. The Oligocene-Miocene sequence, as recognized by Arnold and Hannibal in their paper, "The marine Tertiary stratigraphy of the north Pacific Coast of America," Proc. Amer. Philos. Soc., vol. 52, 1913, pp. 573-589, was, beginning at the base:

1. The Sooke formation.
2. The San Lorenzo formation.
3. The Seattle formation.
4. The Twin River formation.
5. The Monterey formation.

We now know, due to the discovery of a vertebrate fauna in the Monterey of Coalinga region (J. C. Merriam: Tertiary vertebrate faunas of the north Coalinga region of California, Amer. Philos. Soc., n. s., vol. xxii, pt. 3, 1915, pp. 21-26), that this epoch of deposition extended into the middle Miocene, and it seems more than probable that the lowest Vaqueros beds are not older than Lower Miocene.

For map showing distribution of Oligocene deposits in Washington, see paper by C. E. Weaver: "Tertiary formations of western Washington," Wash. State Geol. Surv. Bull. 13, 1916, pp. 13-271.

this general horizon. This fauna is much better known in Oregon and Washington than in California; the beds of this age in these northern areas are not, as a rule, so highly folded and faulted, thus giving more favorable conditions for preservation. In California, on the other hand, the stratigraphic relationships are more easily determined, due to the semi-arid climatic conditions which have been the cause of better exposure.

FAUNAL ZONES

In Washington three fairly distinct faunas are found in the 10,000 feet or more of sediments, which are considered of Oligocene age. These, beginning with the oldest, will be referred to as the faunas of the Agasoma acuminatum beds, of the Molopophorus lincolnensis zone, and of the Acila gettysburgensis zone. The stratigraphic equivalent of these faunal zones, as described by Arnold and Hannibal,[6] are the Sooke, San Lorenzo, and Seattle formations respectively. The lowest of these faunas, that of the Agasoma acuminatum beds or Sooke formation, has been found at a number of localities in Oregon, Washington, and Vancouver Island, and in every place where the stratigraphic relationships could be determined it is in beds below those of the Molopophorus lincolnensis zone. The two faunas are very different, few species being common to the two. However, the beds containing this lower fauna appear to grade up into those of the other horizon, and in no locality studied have they been found to have any great thickness. For this reason it is probable that the former fauna is a facies of the latter. Apparently the difference between the fauna of the Agasoma acuminatum beds and that of the Molopophorus

[6] Ralph Arnold and Harold Hannibal: "The marine Tertiary stratigraphy of the north Pacific Coast of America," Proc. Amer. Philos. Soc., vol. 52, 1913, pp. 573-589.

These formational names were used by Arnold and Hannibal in a faunal rather than a stratigraphic or lithologic sense. Originally they recognized four divisions between the Eocene and the Monterey—the Sooke, San Lorenzo, Seattle, and Twin River formations. C. E. Weaver has apparently shown that the beds forming the Twin River formation are a part of their Seattle formation, which has been repeated by folding. See "The Oligocene of Kitsap County, Washington," Proc. California Acad. Sci., 4th ser., vol. vi, no. 3, 1916, pp. 41-52. The name Agasoma acuminatum beds is used here for the first time. As will be seen from the discussion further on in the paper, it is still doubtful whether the fauna in these beds belong to a zone distinct from the Molopophorus lincolnensis zone. This latter name was first used by C. E. Weaver in his Tertiary faunal horizons of western Washington, Univ. Wash. Publ. Geol., vol. 1, no. 1, 1916, pp. 4-6. Weaver divided the fauna of the San Lorenzo, as recognized by Arnold and Hannibal, into two horizons, which he called the Lincoln and Porter horizons and to which he also applied the names Molopophorus lincolnensis and Turritella porterensis zones. Later work by Doctor Weaver and his students has shown that the faunas of the Lincoln and Porter beds are much more similar than was at first supposed, and that in all probability they are contemporaneous faunas. Thus only one faunal zone can be recognized; for this it is agreed that the name Molopophorus lincolnensis zone should be used.

lincolnensis zone is due, in large part, to differences in the temperature of the waters in which the faunas lived. The former fauna undoubtedly existed under more temperate conditions than did the latter. This is shown by the fact that a number of the species in the Agasoma acuminatum beds show very close affinities with certain species which are now living off the coast of Vancouver Island, Washington, and Oregon. The fauna of the Molopophorus lincolnensis zone is more tropical in character, containing a fairly large number of species which are closely related to

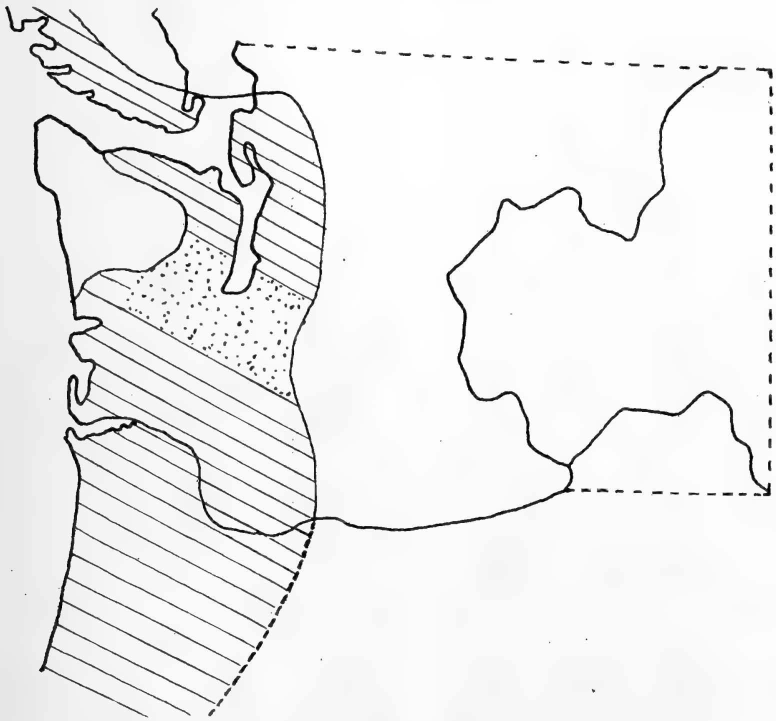

FIGURE 3.—*Outline of Oligocene Sea in Washington*

Tejon (Upper Eocene) species, and if we should look for their recent affinities we would expect to find them in the tropical and subtropical waters off the coasts of Lower California, Central and South America.

The latest of the Oligocene faunas in Oregon, Washington, and Vancouver Island is that from the Acila gettysburgensis zone. The beds in which the Acila gettysburgensis fauna is found are several thousand feet in thickness. On Vancouver Island and in the vicinity of Restoration Point, near Port Blakeley, heavy conglomerates are found which sepa-

rate this fauna from that of the Molopophorus lincolnensis zone. Later work[7] may possibly show that here we are dealing with two distinct epochs of deposition. This Acila gettysburgensis fauna also is very different from that of the Molopophorus lincolnensis zone, as well as being decidedly different from that of the Agasoma acuminatus beds. However, considerably fewer species are known from the Acila gettysburgensis zone than from the Molopophorus lincolnensis zone, and it may be that the difference between the two faunas is more apparent than real.

CLIMATIC CONDITIONS

R. E. Dickerson,[8] in a recent publication, has expressed the opinion that the fauna of the Acila gettysburgensis zone lived under more temperate conditions than that of the Molopophorus lincolnensis zone. We are left to infer from that that very probably the big difference between these two faunas is due to temperature rather than to the time factor. That Dickerson's observations are, at least in part, true is apparently shown by the work of B. L. Clark on the fauna of the San Lorenzo of middle California. Here in the same beds is found a considerable number of species which in Oregon, Washington, and Vancouver Island have been found only in the Agasoma acuminatus beds, the Molopophorus lincolnensis zone, or the Acila gettysburgensis zone, thus showing that apparently all three faunas are more closely related in time than was indicated by the data obtained from the northern localities. Some of the species, which in the northern localities have been found in distinct zones, are found in California associated in the same horizon. As these species are highly ornamented gastropods, forms which one might expect to have a rather short life period, they indicate nearly the same, if not identical, age.

This intermingling in the California localities of certain of the species of the three faunas as recognized in the northern areas, as cited above, suggests very strongly that in the southern localities conditions of temperature existed which were intermediate between the temperature conditions which existed during the accumulation of the Agasoma acuminatum beds and the beds of the Acila gettysburgensis zone and the more tropical conditions represented by the deposits of the Molopophorus lincolnensis

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[7] If this should prove to be the case, the lower beds would be referred to the San Lorenzo Group, the upper to the Seattle Group. However, at the present time we do not propose such a classification. The name Acila gettysburgensis zone was first used by Weaver in the paper already referred to.

[8] R. E. Dickerson: Climate and its influence upon the Oligocene faunas of the Pacific Coast, with descriptions of some new species from the Molopophorus lincolnensis zone. Proc. California Acad. Sci., 4th ser., vol. vii, no. 6, 1917, pp. 162-163.

zone, thus giving what might be expected, an interfingering of certain elements of the three faunas.

EOCENE-MIOCENE RELATIONSHIPS

Of the three Oligocene faunas, that of the Molopophorus lincolnensis shows a closer relationship to the fauna of the Tejon (Upper Eocene). A considerable number of the species of the Molopophorus lincolnensis zone are undoubtedly closely related to certain Tejon species. The Eocene character is also shown in the close similarity of the generic assemblage. C. E. Weaver has listed several highly ornamented gastropods in the Molopophorus lincolnensis zone as common to the Tejon fauna. On the other hand, the Agasoma acuminatum fauna, which is found in deposits lower stratigraphically than that of the Molopophorus lincolnensis zone, has nothing in common with that of the Tejon; its fauna is more Miocene in character, so much so that when first described it was considered to be of later Miocene[9] age than the Monterey (Lower Miocene). The highest of the Oligocene faunas, that of the Acila gettysburgensis zone, is also more closely related to the fauna of the Miocene than to that of the Eocene.

Undoubtedly these Miocene and Eocene relationships of the Oligocene faunas, just pointed out, are very largely the result of differences of temperature conditions. During Tejon periods tropical conditions prevailed and the tropical marine faunas held sway well up into northern waters. The Agasoma acuminatum fauna, which follows that of the Tejon, represents more temperate conditions of deposition. The Eocene representatives of this fauna very probably were living during the Eocene period in the region of the Arctic Circle. Following this the waters, at least locally, as shown by the character of the fauna of the Molopophorus lincolnensis zone, were again much warmer and tropical species replaced the temperate forms, to be later replaced by a more temperate fauna during the deposition of the beds of the Acila gettysburgensis zone. At the present time we can not say for a certainty that the Oligocene fauna everywhere followed in the sequence as outlined above. As has already been stated, it is still an open question whether the Agasoma acuminatum fauna and that of the Molopophorus lincolnensis zone belong to distinct horizons, the Oligocene opening with temperate conditions, later to be followed by tropical, or whether these two faunas were contemporaneous, the differences in temperature being local and the two faunas living in

[9] J. C. Merriam: Note on two Tertiary faunas from the rocks of southern coast of Vancouver Island. Univ. of California Publ. Bull. Dept. Geol., vol. 2, no. 3, 1896, pp. 101-108.

the same general areas. We find the same difficulty in evaluating the causes of the differentiation of the Molopophorus lincolnensis fauna and that of the Acila gettysburgensis zone.

We may say with certainty, however, that during the Oligocene on the West Coast we find the beginning of conditions like those which existed during the Miocene and Pliocene, a beginning of the differentiation of the climatic zones, which were not defined during the Eocene, and with it the local differentiation of faunas, due to temperature barriers—a condition which did not exist to any appreciable extent during the Eocene.

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AMSDEN FORMATION OF THE EAST SLOPE OF THE WIND RIVER MOUNTAINS OF WYOMING AND ITS FAUNA *

BY E. B. BRANSON AND D. K. GREGER

(*Presented in abstract before the Society December 29, 1916*)

CONTENTS

Distribution of the Amsden

The Amsden formation was described by Darton[1] in 1904 from its outcrops along the Amsden River on the east slope of the Big Horn Mountains in northern Wyoming. Since then he has described and mapped it along the Wind River Mountains from Circle on the north to south of Dallas on the south, in the Rattlesnake Mountains, and in the Owl Creek Mountains, and Blackwelder writes of its occurrence in southern Montana. According to Blackwelder, "it can be followed with more or less confidence clear across the State (Wyoming) from the Black Hills to Idaho." [2] Only the Amsden of the east slope of the Wind River Mountains from Bull Lake southward is treated in this paper.

Age of the Amsden

Darton has called the upper Amsden Pennsylvanian, on the basis of fossils collected from near Leo and Shirley, and the lower part probably Mississippian. Blackwelder[3] has found two faunas in the Gros Ventre

* Revised manuscript received by the Secretary of the Society April 2, 1918.
[1] Bull. Geol. Soc. Am., vol. 15, pp. 396-397.
[2] Am. Jour. Sci., vol. 36, 4th ser., p. 175.
[3] Bull. Geol. Soc. Am., vol. 19, pp. 414-415.

Range, one of which is Pennsylvanian and the other Mississippian, according to Girty.[4] Data presented in this paper indicate the homotaxy of the Amsden of the east side of the Wind River Mountains and the Sainte Genevieve of the Mississippi Valley.

Fossil Horizons and Locations

Several years ago Mr. N. H. Brown, of Lander, Wyoming, called Mr. Branson's attention to some fossils that he had collected in outwash from an irrigation ditch a few miles south of Lander, and in 1911 Branson collected some of these, but could not find from whence they came, though the probable source was the Amsden. In 1913 the fossils were found in place a few miles south of the Little Popo Agie River, in the Wind River Mountains, and collections were made from several localities. In 1916 Branson made a small collection in the Bull Lake region northwest of Lander and further collections in the Little Popo Agie region.

The fossilization differs sharply in different regions. Near Bull Lake the fossils are of calcite and poorly preserved; at one place south of the Little Popo Agie they are all silicified and the silica is often highly colored, while three miles from the silicified fossils the preservation is mainly in hematite.

In the Popo Agie region the exact horizon of the fossils was not determined, as both the top and bottom of the formation are covered. Good exposures of the Amsden seem to be absent from the southern Wind River Mountains, and at the best the outcrops consist of a few feet of rock in place. In section 19, township 31 north, range 99 west, about four miles south of the Little Popo Agie canyon, more than three feet of sandy, highly ferruginous shales outcrop about 60 feet from the base of the formation. In places these shales grade into a concretionary iron ore, and fossils occur above them and probably in and below them. Above they are in a yellow, impure limestone, and in a red to purple impure limestone. The purple limestone was not found in place, but in the float in the same locality as the red shales. The fossils occur weathered out on the slopes for about 20 feet above the shales.

Section and Description of the Amsden

There are exposures of the entire formation in vertical cliffs in the Bull Lake region. The iron, sandstone, and shales of the Popo Agie region do not appear and the rock is mainly dolomite and limestone. The following

[4] Am. Jour. Sci., vol. 37, 4th ser., pp. 175-176.

is a section four miles west of Bull Lake, in section 11, township 2 north of the Wind River base line, range 4 west of the Wind River meridian.

The contact between the Amsden and the overlying Tensleep is one of disconformity, with a clear-cut wavy line of demarcation.

1. Compact, fine-grained, light-gray limestone	8 feet 2 inches
2. Buff, fine-grained, sandy limestone	4 feet
3. Buff, compact, sandy, thin-bedded limestone much like 1 and 2 but without the gray. The lower part weathers to a pinkish color while retaining its strength and compactness	14 feet
4. Dark-gray, compact, hackly limestone	7 feet 6 inches
5. Dark-gray, friable, coarsely crystalline limestone, interbedded with thin, discontinuous layers of darker gray, compact limestone, fossiliferous	23 feet
6. A heterogeneous mixture of limestone, sandstone, shale, and conglomerate in a peculiar arched structure. The under part of the arches weathers out, leaving caves. At the bottom occurs a conglomerate which generally contains many fragments of Madison. In many places breccias resulting from cave-filling occur. Contact with the Madison sharp, disconformable	20 feet
Total	76 feet 8 inches

Measurements were made on the face of a vertical cliff, excepting the last 20 feet, which was estimated, because the top could not be reached.

Many caves occur at the base of the Amsden, and in early Pennsylvanian time the caves were more extensive than at present. In the Bull Lake region the base consists of a thin, irregular basal conglomerate, above which there is a dolomite containing old caves filled with large, angular fragments of Amsden limestone mixed with greenish shale and lenticular sandstone beds. Only one filled cave was noted near the top of the formation and it was filled with sand, like that of the overlying Tensleep, the sand occurring as filling matter between Amsden boulders. The sand in the caves near the base also resembles the Tensleep and occurs as filling matter, indicating that the caves were formed in pre-Tensleep time and filled during the Tensleep. Where the base of the Amsden is well exposed the lower 20 to 30 feet appear as a series of arches with the overlying beds overhanging. The tops and sides of the old caves form the tops and sides of the present arches and the old cave-fillings have weathered back, forming reentrants. A coarsely crystalline bed of limestone, 3 to 4 feet thick, that is highly fossiliferous, occurs 35 feet from the top, but fossils were not found in any other bed.

Faunas and Correlations

Three men spent about five hours in collecting in the locality where the section was made, and specimens of the following species were obtained: *Zaphrentis amsdenensis, Spirifer pellænsis, Spirifer shoshonensis, Composita trinuclea, Eumetria marcyi, Pugnoides ottumwa, Spiriferina browni, Orthotetes kaskaskensis, Chonetes chesterensis, Tetracamera subcuneata, Phillipsia* sp.?

In the Little Popo Agie region, where all of the fossils were collected on the weathered slopes, the fauna consists of the following species:

Zaphrentis amsdenensis
Ortonia cf. *blatchleyi*
Orbiculoidea wyomingensis
Composita trinuclea
Diaphragmus phillipsi
Spirifer welleri
Spirifer pellænsis
Pustula genevievensis
Spiriferina browni
Martinia sp.?
Eumetria verneuiliana
Pugnoides ottumwa
Orthotetes kaskaskiensis
Schizophoria swallovi
Cliothyridina hirsuta
Meekella amsdenensis
Bulimorpha canaliculata
Loxonema wortheni
Bucanopsis or *Bellerophon*
Myalina sancti-ludovici
Microdon cf. *oblongus*
Crinoid
Orthoceras

The most abundant forms in the Wind River Amsden are *Composita trinuclea, Spirifer pellænsis, Diaphragmus phillipsi, Spirifer welleri, Zaphrentis amsdenensis,* and *Spiriferina browni.*

Composita trinuclea, Eumetria verneuiliana, Spirifer pellænsis, Pugnoides ottumwa, and *Orthotetes kaskaskiensis* are positively identified on the basis of minute characters. All of these species occur in the Sainte Genevieve of the Mississippi Valley and none of them ranges below the Salem. The Salem species, *Tetracamera subcuneata* and *Bulimorpha bulimiformis,* are not identified with equal positiveness, but the evidence of most of the species indicates that the Amsden should be correlated with the Sainte Genevieve.

On the other hand, if the Amsden is of the same age as the Sainte Genevieve, *Meekella,* represented by *M. amsdenensis,* occurs earlier here than any place else in America. But *M. amsdenensis* is a non-plicate form, and in this respect is similar to *Meekella leei,* from the Lower Carboniferous[5] of England, and differs from the Pennsylvanian Meekellas.

Pustula genevievensis has often been identified as *Productus nebraskensis,* but agrees better with the Sainte Genevieve form.

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[5] Memoirs of the Geological Survey of Great Britain. Paleontology, vol. 1, part 2, pp. 112-114, pl. 13, figs. 1-2.

An unidentified coral that resembles *Chætetes milliporaceous,* of the Pennsylvanian of the Mississippi Valley, is a disturbing element in drawing positive conclusion, but we do not attach great importance to it.

Blackwelder's list of Amsden species from the Gros Ventre Mountains contains no species identified by us from the Wind River. However, our *Composita trinuclea* may be the same as his *C. subtilita* as Compositas, scarcely to be distinguished, range from the Amsden to near the top of the Embar (Permian). *Productus nebraskensis* of the Gros Ventre may be the same as the form identified by us as *Pustula genevievensis. Schizophoria* aff. *resupinoides* may be our *S. swallovi.*

The evidence of the fossils indicates that the Wind River Amsden is probably older than the Gros Ventre Amsden. It is possible that the two were contemporaneous, but that the Wind River basin was connected with the interior basin and the Gros Ventre was not.

Description of Species

ZAPHRENTIS AMSDENENSIS n. sp.

Plate 19, figures 19–20

Corallum horn-shaped, circular in cross-section, slightly curved, sides diverging at an angle of about 30 degrees. Surface marked by inconspicuous wrinkles, unequally spaced. Calyx shallow; fossula indistinct on the shorter, concave side of the corallum; septæ averaging 36, approaching the center in pairs, but leaving a small central area clear.

Dimensions of largest specimen collected: Length, 51 millimeters; diameter, 24 millimeters; average specimens, length, 35 millimeters; diameter, 15 millimeters; smallest specimens, length, 14 millimeters; diameter, 8 millimeters.

Z. amsdenensis differs from *Z. pellœnsis,* probably the most closely related species, in the absence of spines, smaller angle of divergence of the sides, and less conspicuous fossula. From *Z. dœli* Milne Edwards and Haime, another closely related species, it differs in the absence of spines and the less conspicuous fossula.

CHÆTETES ?

Plate 19, figures 21–22

Three fragments of a form resembling *Chœtetes milliporaceous* were collected. The best preserved specimen is silicified and details of structure are obscure or absent. No connecting pores have been observed. The small size of the corallites and their angular shape, triangular to hexagonal, give the species a close resemblance to *Chœtetes milliporaceous.*

BRYOZOANS

A few fragments too imperfect for generic reference were collected; one group is fenestelloid and another batastomelloid in appearance.

ORBICULOIDEA WYOMINGENSIS n. sp.

Plate 19, figures 7 and 8

Cotypes three specimens from Bull Lake Creek. Shell subcircular in outline; brachial valve with apex about one-fourth the diameter from the posterior margin; surface in front of apex parallel to plane of valve for about one-half the diameter of the shell, thence sloping gently to the anterior margin. Laterally from the apex the sides are gently concave, behind the apex strongly concave. Surface marked by ordinary, concentric lines of growth, 2 to 3 to the millimeter. Pedicle valve with apex a short distance anterior to the center of the shell. Shell slightly convex. Delthyrium extending from apex three-quarters of the distance to the posterior margin of the valve; gradually narrowing posteriorly; completely closed by the listrium. Lines of growth like those on the brachial valve. Diameter of the larger specimen about 25 millimeters, of the smaller specimens 15 millimeters and 16 millimeters.

ORTHOTETES KASKASKIENSIS (McChesney)

Plate 19, figures 3 and 4

1860. *Orthis kaskaskiensis* McChesney, Descriptions of New Paleozoic Fossils, page 31.

1892. *Derbya kaskaskiensis* Hall and Clark, Paleontology of New York, volume 8, part 1, plate 11*b*, figure 6.

1914. *Orthotetes kaskaskiensis* Weller, Monograph 1,[6] Illinois Geological Survey, page 77, plate 6, figures 1–14.

1916. *Orthotetes kaskaskiensis* Weller, Contributions from Walker Museum, volume 1, number 10, pages 245–246, plate XVI, figure 1.

The specimens of this species from the Amsden are slightly larger than examples from the Pella beds of Fort Dodge, Iowa. They agree more fully with specimens from the Saint Louis oolite of Lewis County, Missouri. The two specimens in the collection measure: Length, 30 millimeters; breadth, 43 millimeters; and length, 32 millimeters; breadth, 46 millimeters.

DIAPHRAGMUS PHILLIPSI (Norwood and Pratten)

Plate 19, figures 5–6

1854. *Productus phillipsi* Norwood and Pratten, Journal of the Academy of Natural Science of Philadelphia, volume 3, second series, page 8, plate 1, figures 2 *a*, *b* and *c*.

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[6] Synonomy given by Weller in the Illinois monograph is not repeated in this paper, but the original reference is given.

1898. *Productus phillipsi* Weller, Bibliographic Index of North American Carboniferous Invertebrates, page 498.
1915. *Productus phillipsi* G. H. Girty, Missouri Bureau of Geology and Mines, volume 13, series 2, page 347.

Original description.—"Shell rather small, nearly as long as broad, dorsal valve slightly gibbous, its anterior part flattened, with a wide shallow sinus on old specimens, while young ones do not show it. The beak, although slightly enrolled on itself, does not pass the cardinal border. The ears are small, flattened, and smooth, showing no trace of either folds or tubes. The surface is covered with coarse, irregularly sized ribs, which are generally broader than the furrows separating them. Many of the ribs are bifurcated. The cardinal line measures four-fifths of the greatest breadth of the shell. The sides fall perpendicularly on the ears. The only traces of tubes are a few indistinct ones on the flanks.

"Ventral valve concave, with a very slight varix. The visceral disk has ribs similar to those on the other valve; beyond the disk they are obliterated, the surface being covered with nine or ten broad lamellæ, the edges of which are turned sharply upward, presenting acute wavy ridges, which are continued on to the cardinal border on each side."

Remarks on Amsden specimens.—The beak passes the cardinal border in some Amsden specimens and in some the ears have incipient folds and a few small spines. Six specimens give the following measurements: Length, 17 to 24½ millimeters; breadth, 20 to 24 millimeters; thickness, 6 to 9 millimeters.

The surface of the pedicle valve is marked by about 28 ribs. Near the anterior border there are from eight to ten ribs in the space of 10 millimeters.

This species may be easily distinguished from any other by the coarse, irregular ribs of the valve and by the visceral portion only of the ventral valve possessing ribs, with broad, ridged lamellæ around it. The pedicle valve does not appear to have possessed an anterior prolongation, as its present front is without one and is bounded by a sharp margin.

Next to *Composita trinuclea* this is the most abundant species in the fauna.

PUSTULA GENEVIEVENSIS (Weller)

Plate 19, figures 1–2

1914. *Echinoconchus genevievensis* Weller, Illinois Geological Survey, monograph 1, pages 140–141, plate 18, figures 1–6.

The collection contains a few poorly preserved specimens of a Pustula that resemble *"Echinoconchus" genevievensis* of Weller. The specimens

are too poorly preserved to show whether there were fine spines on the concentric raised lines, and the concentric lines are indistinct on most of the exfoliated surfaces. The measurements of the specimen figured are: Length, 23 millimeters; greatest breadth, 27 millimeters.

MEEKELLA AMSDENENSIS n. sp.

Plate 18, figures 22–25

Shell slightly smaller than in *M. striatocostata,* longer than broad, the greatest width near the anterior margin. Length from umbonal region to front margin, 25 millimeters; greatest breadth, 23 millimeters; thickness, 17 millimeters.

Pedicle valve convex, with umbo prominent, eccentric, flattened. Cardinal area narrow and high, relation about 16 to 9, with the delthyrium occupying about one-fourth of the area. Surface marked by numerous minute costæ, subequal in size, separated by slightly wider interspaces, and increasing toward the margin, in the main by intercalation, but also by bifurcation. About three costæ to the millimeter.

Brachial valve more convex than the pedicle, subcircular, strongest slope toward the hinge line. Surface marked by costæ similar to those on the pedicle valve.

Internally the pedicle valve bears two parallel dental plates, about one millimeter apart, which extend forward about half the length of the valve.

This is the first Meekella reported from below the Pennsylvanian in America and, like the Lower Carboniferous Meekellas of England, it lacks plications.[7]

SPIRIFERINA BROWNI n. sp.

Plate 18, figures 15 and 17

Shell below medium size; broader than long; the greatest width a short distance in front of the hinge line; cardinal extremities rounded. The dimensions of a nearly perfect specimen of medium size are: Length, 15 millimeters; breadth, 18 millimeters; thickness, 10.5 millimeters; height of cardinal area, 2.4 millimeters.

Pedicle valve strongly convex, most prominent in the umbonal region; each lateral slope marked by 6 to 7 rounded to subangular plications. Mesial sinus sharply defined, rounded; beaks small, slightly incurved; cardinal area well developed, concave; delthyrium as wide as high. Internally a strong median septum reaches half the length of the valve, and the dental plates are about half the length of the median septum.

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[7] Memoirs of the Geological Survey of Great Britain. Paleontology, vol. 1, part 2, pp. 112-114, pl. 13, figs. 1, 2.

Brachial valve less convex than the pedicle; highest at the front of the fold; each lateral slope marked by 6 to 7 rounded plications. Mesial fold sharply defined, rounded, much elevated in front. Cardinal area very narrow and nearly at right angles to that of the pedicle valve. Beak small, incurved. Lines of growth not imbricating.

This is the only species of *Spiriferina* found in the fauna. It differs from *S. salemensis* in the greatest width being in front of the hinge line, the cardinal extremities being rounded, cardinal area much lower and narrower, mesial sinus rounded, delthyrium wider compared to height, usually one or two more plications on each side of a valve, median septum longer and mesial fold rounded. It differs from *S. spinosa* in lacking the spines, in the median septum being larger, and the cardinal extremities never being angular.

SPIRIFER PELLÆNSIS (Weller)

Plate 18, figures 7–9

1914. ***Spirifer pellænsis* Weller, Illinois State Geological Survey, monograph 1, pages 340–341, plate 45, figures 1–31.**

This species is abundant and has a wide variety of shapes and sizes. The number of plications is fairly constant, varying from 18 to 22 on the pedicle valve in 25 specimens chosen at random. Usually there is one well developed plication in the sinus and two weaker plications formed by the bifurcation of the marginal plications. Some specimens show three well developed plications in the sinus and two weaker plications formed as mentioned above. Most of the forms from the Amsden agree with Weller's description, but there is one distinct variation in which the hinge line is constantly longer than the shell, and the fold is much more elevated than in the type.

Measurements of eight typical specimens show an average length of 19.9 millimeters; breadth, 26.5 millimeters; thickness, 12.7 millimeters. Measurements of four of the other variety show average length, 20 millimeters; breadth, 36 millimeters; thickness, 16.5 millimeters.

The typical forms are much the more abundant in the fauna and the larger variety is relatively rare.

SPIRIFER WELLERI n. sp.

Plate 18, figures 10, 11, and 16

Shell below medium size; length and breadth subequal; greatest breadth in front of the hinge line; cardinal extremities rounded. The average size of eight full-grown specimens is: Length, 16 millimeters; breadth, 17.6 millimeters; thickness, 10.4 millimeters.

Pedicle valve strongly convex, with greatest convexity opposite the hinge line; beak strongly incurved; cardinal area high, short, height and breadth as 1 to 3. Cardinal area not sharply defined, but with the shell rounding to meet the area; lateral slopes of the valve convex, marked by 9 to 11 subangular to rounded plications. The mesial sinus is broad and shallow and originates at the beak; a median plication starts at the umbone and increases in size backward; two plications come into the sinus by bifurcation of the marginal plications, and these may remain small or become subequal to the median plication.

Brachial valve much less convex than the pedicle. The mesial fold which originates at the beak is set off from the rest of the shell by grooves that are deeper and wider than those between the plications. Near the beak the fold is not elevated above the rest of the shell, but anteriorly it becomes prominent. A median furrow originates at or near the beak, and two shallower, lateral furrows originate about the middle of the fold.

Remarks.—In our earlier work on the Amsden we included this form with *S. pellænsis,* but we now give it species rank on account of the constantly short hinge line and high and narrow area. It is the most abundant Spirifer in the Amsden.

SPIRIFER SHOSHONENSIS n. sp.

Plate 18, figures 26 and 27

Shell of medium size; wider than long; greatest breadth at hinge line. Width of largest specimen, 50 millimeters; of smallest specimen, 29 millimeters; length of largest specimen, 32 millimeters; of smallest, 12 millimeters. Thickness of pedicle valve of largest specimen, 12 millimeters.

Pedicle valve strongly convex; greatest convexity a little in front of the hinge line; beak strongly curved and projecting about one-fourth of the length of the valve beyond the hinge line. Lateral slopes of the pedicle valve convex, each marked by about 17 rounded plications. The first eight lateral plications on each slope are formed by the bifurcation of plications near the back of the valve. The plications outside of the first eight do not bifurcate. The mesial sinus is shallow and poorly defined. A median plication starts at the umbone, increases slightly in size forward, and in some specimens bifurcates. Two plications come into the sinus near the umbone by bifurcation of the marginal plications and become subequal in size to the median plication.

Brachial valve much less convex than the pedicle. Greatest convexity near the middle of the valve, with lateral slopes and front slope subequal. Each lateral slope is marked by about 15 subangular to rounded plica-

tions, the first eight of which are formed by bifurcation of four plications. The plications outside of the first eight do not bifurcate. The mesial fold originates at the beak and is set off from the rest of the shell by grooves that are deeper and wider than those between the plications. The fold is narrow and elevated near the front margin of the shell. Two plications on the fold originate at the beak and each subdivides into three or four before reaching the front margin.

MARTINIA n. sp.

Plate 19, figures 17–18

The collection contains a single example of a shell that agrees, in general, with the genus Martinia. Its dimensions are: Length, 9.5 millimeters; breadth, 6.5 millimeters; greatest thickness, which is in the umbonal region, 4.5 millimeters. Absence of growth lines suggests an immature shell. Compared with the Mississippi Valley species, *M. contracta* and *M. sulcata,* the most striking difference is the greater length over breadth.

PUGNOIDES OTTUMWA (White)

Plate 18, figures 12–14

1862. *Rhynchonella ottumwa* White, Proceedings of Boston Society of Natural History, volume 9, page 23.
1914. *Pugnoides ottumwa* Weller, Illinois Geological Survey, monograph 1, pages 193–195, plate 25, figures 7–17.
1916. *Pugnoides ottumwa* Weller, Contributions from Walker Museum, volume 1, number 10, page 246, plate XVI, figures 7–8.

This species is common, but most of the specimens are not well preserved. It agrees with Weller's description, but seems to average a little narrower compared to the length. The means of the measurements of seven typical specimens are: Length, 11 millimeters; breadth, 11.2 millimeters; thickness, 6.2 millimeters. A young specimen, 8 millimeters long, 8 millimeters wide, and 4 millimeters thick, has no plications on the fold and in the sinus and has incipient plications on the margins.

COMPOSITA TRINUCLEA (Hall)

Plate 18, figures 1–4, 9

1856. *Terebratula trinucleus* Hall, Transactions of Albany Institute, volume 4, page 7.
1914. *Composita trinuclea* Weller, Illinois State Geological Survey, monograph 1, page 486, plate 81, figures 16–45.
1916. *Composita trunclea* Weller, Contributions from Walker Museum, volume 1, number 10, page 246, plate XVI, figures 3–6.

This species is three to four times as abundant as any other in the fauna. It is referred to *C. trinuclea,* though the larger forms might with equal propriety be referred to *C. subquadrata.* The means of the measurements of a series of eight specimens are: Length, 18.5 millimeters; breadth, 16.2 millimeters; thickness, 10.7 millimeters.

There are many smaller specimens in the collection, but they are probably immature and show practically the same ratio of length, breadth, and thickness as those measured. The largest specimen measured had a length of 21 millimeters; breadth, 19 millimeters; thickness, 13 millimeters, and the smallest: Length, 16 millimeters; breadth, 14 millimeters; thickness, 9 millimeters. Some specimens show rather wide variations from the type, one having a length of 22 millimeters; breadth, 12.5 millimeters; thickness, 14 millimeters. Some forms show distinct furrows on either side of the fold, while in others this feature is entirely lacking. An arranged series would show all gradations from the deep furrows to the absence of furrows.

EUMETRIA VERNEUILANA (Hall)

Plate 18, figures 20–21

1856. *Retzia verneuiliana* Hall, Transactions of Albany Institute, volume 4, page 9.

1914. *Eumetria verneuiliana* Weller, Illinois Geological Survey, monograph 1, pages 442–444, plate 76, figures 18–24.

Only eight specimens of this species were collected. They agree with Weller's figures and descriptions excepting in the number of plications being slightly smaller. Weller gives the usual number as 46 to 50, while the eight specimens show brachial 36 to 42 and pedicle 36 to 40.

CLEIOTHYRIDINA HIRSUTA (Hall)

Plate 19, figure 14

1856. *Spirifera hirsuta* Hall, Transactions of Albany Institute, volume 4, page 8.

1914. *Cliothyridina hirsuta* Weller, Illinois Geological Survey, monograph 1. pages 479–480, plate 80, figures 13–24.

Two specimens from the Amsden are in the University of Missouri collection.

TETRACAMERA SUBCUNEATA (Hall)

Plate 18, figure 18

1856. *Rhynchonella subcuneata* Hall, Transactions of Albany Institute, volume 4, page 11.

1914. *Tetracamera subcuneata* Weller, Illinois Geological Survey, monograph 1. pages 214–215, plate 28, figures 13–24.

Two imperfect specimens of this species were collected from the Amsden, and the reference to *T. subcuneata* Hall is provisional.

SCHIZOPHORIA SWALLOVI ? (Hall)

Plate 19, figures 12–13

1858. *Orthis swallowvi* Hall, Geological Survey of Iowa, volume 1, part 2, page 597, plate 12, figures 5*a*-*b*.
1914. *Schizophoria swallovi?* Weller, Illinois State Geological Survey, monograph 1, pages 167–168, plate 22, figures 1–6.

This is one of the rare fossils in the association. A single immature specimen, with conjoined valves, is illustrated. Fragmentary specimens in the collection show that the species reached the following dimensions: Length, 36 millimeters; breadth, 34 millimeters; thickness, 26 millimeters. This species has not hitherto been recorded from above the Burlington, but specimens from the Saint Louis of Knox County, Missouri, are in Mr. Greger's collection.

CHONETES CHESTERENSIS (Weller)

Plate 18, figure 19

1915. *Chonetes chesterensis* Weller, Illinois Geological Survey, monograph 1, page 83, plate 8, figures 31–34.

Only one specimen was collected from the Amsden. It is referred to *C. chesterensis,* though it seems to agree as well with *C. cherokeensis* Snider.[8]

ORTONIA cf. *BLATCHLEYI* (Cumings and Beede)

Plate 18, figure 15

1905. *Ortonia blatchleyi* Cumings and Beede, Indiana Department of Geology and Natural Resources, thirtieth annual report, page 1273, plate 19, figure 8.

Only one specimen of this species was collected. It is approximately 5 millimeters long and 1½ millimeters wide at the open end. Attached for the entire length; trumpet-shaped; the small end bent; strong annulations, but overlapping not determinable. Agrees in most respects with *Ortonia blatchleyi.*

MICRODON cf. *OBLONGUS* (Hall)

Plate 19, figures 25 and 11

1856. *Cypricardella oblonga* Hall, Transactions of the Albany Institute, volume 4, page 18.

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[8] Oklahoma Geological Survey, Bulletin 24, p. 77, pl. iii, figs. 16-18.

Only one specimen was collected. It agrees with *M. oblongus,* save in the shape of the anterior end, which is less prominent than in the type. Figure 25 does not represent the lateral ridge as prominently as it shows in the specimen. Figure 11 may be of an internal mold of this species, but there is no way of making this determination positive.

MYALINA SANCTI-LUDOVICI (Worthen)

Plate 19, figure 26

1873. *Myalina St. Ludovici* Worthen, Geological Survey of Illinois, volume 5, page 540, plate 22, figure 3.
1894. *Myalina sancti-ludovici* Keyes, Missouri Geological Survey, volume 5, page 117.
1898. *Myalina sancti-ludovici* Weller, Carboniferous Invertebrates, page 364.
1909. *Myalina sancti-ludovici* Grabau, North American Index Fossils, volume 1, page 453, figure 600.

Six specimens of this species are in the collection. The largest, 20 millimeters in greatest length and a little more than 12 millimeters along the hinge line, is almost two-thirds the size of the type. A series of four measurements on the drawings of the type and on this shell showed: Length of type, 30 millimeters; Amsden shell, 20 millimeters; hinge-line of type, $17\frac{1}{2}$ millimeters; Amsden, 12 millimeters; end of hinge line to lower side of shell: Type, $25\frac{1}{2}$ millimeters; Amsden, 15 millimeters; width of type, 15 millimeters; Amsden, 10 millimeters. The greatest thickness, 10 millimeters, is near the beaks.

In some of the specimens the beaks project above the hinge line, but the prominence of the umbones makes this almost inevitable when the shells are slightly crushed, and we do not regard this characteristic as of specific value. The specific reference is not considered as certain.

BULIMORPHA CANALICULATA Hall

Plate 19, figure 15

1856. *Bulimella canaliculata* Hall, Transactions of the Albany Institute, volume 4, page 29.
   Polyphemopsis canaliculata (Hall) Meek and Worthen, Geological Report of Illinois, volume 2, page 372.
1882. *Bulimorpha canaliculata* Whitfield, Bulletin of the American Museum of Natural History, volume 1, page 74, plate 8, figure 41.
1883. *Bulimorpha canaliculata* Hall, Twelfth Report of the Geological Survey of Indiana, page 367, plate 31, figure 41.
1889. *Bulimorpha canaliculata* Keyes, Proceedings of the Academy of Natural Science of Philadelphia, page 300.
1898. *Bulimorpha canaliculata* (Hall) Weller, United States Geological Survey, bulletin 153, page 151.

1905. *Bulimorpha canaliculata* Cumings and Beede, Department of Geology and Natural Resources of Indiana, thirtieth annual report, page 1343, plate 25, figure 41.

Three imperfect specimens were collected. Two specimens lack the tip of the apical coil and part of the first coil, and one is slightly crushed. The spire angle, 41 to 45 degrees, is the same as in *B. canaliculata,* and in other respects the specimens agree with that species.

PALEONEILO AMSDENENSIS n. sp.

Plate 19, figures 23–24. Text figures 1–2

Twenty-five specimens, most of which are fragmentary, are in our collections. All of the specimens but one have the shell removed. In general outline the shell is subelliptical, but the posterior end is about two-thirds as wide as the anterior. Length of shell, about 17 millimeters; greatest height at umbones, 9 millimeters; greatest thickness directly below the umbone, 5 millimeters.

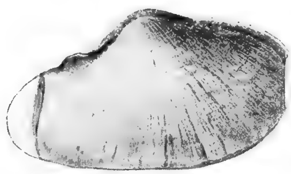


FIGURE 1.—*Enlarged Drawing of Paleoneilo amsdenensis*

Shows ornamentation Enlarged about 2½ diameters.

The beaks are subcentral, but are slightly nearer the anterior end and are directed toward the posterior end. Both extremities are gaping. The posterior extremity is pinched and much thinner than the anterior.

The shell is marked by unequally spaced growth lines, which are crossed by very fine irregular lines that radiate from the beaks and are most prominent on the umbones. The specimen that retains the shell is the only one that has these lines preserved. A short external ligament was present.

The dentition is taxodont and not interrupted below the beaks. The teeth are longest at the beaks and broadest behind the beaks. About 16 teeth are present and the number is about the same in front and behind the beaks.

Musculature obscure in the types.

Our specimens resemble Girty's figures of *Yoldia glabra,*[9] but the radiating lines are not mentioned in descriptions or shown in figures of that species. The dentition differs, as shown in plate 19, figure 24, of this paper, and plate 13, figure 9*a* of Girty's paper. Evidences of an external ligament are clear in our species and are doubtful in Girty's.

[9] Fauna of the Wewoka formation of Oklahoma, pl. 13, figs. 9-15.

BUCANOPSIS or *BELLEROPHON*

Plate 19, figures 9–10

Two interior casts representing two species of Bucanopsis or Bellerophon were collected at locality number 1.

LOXONEMA WORTHENI (Weller)

Plate 18, figure 6

1916. *Loxonema wortheni* Weller. Contributions from Walker Museum, volume 1, number 10, page 261, plate XVIII, figures 18–20.

Originally we identified our fragmentary specimens with *Loxonema yandellana* Hall, but they agree with Weller's species, *L. wortheni,* described in 1916, in every detail.

CYCLOCERAS sp.?

One fragment that resembles *Cycloceras sequoyahensis* Snider was collected.

ORTHOCERAS sp.?

A few specimens too fragmentary for identification were collected.

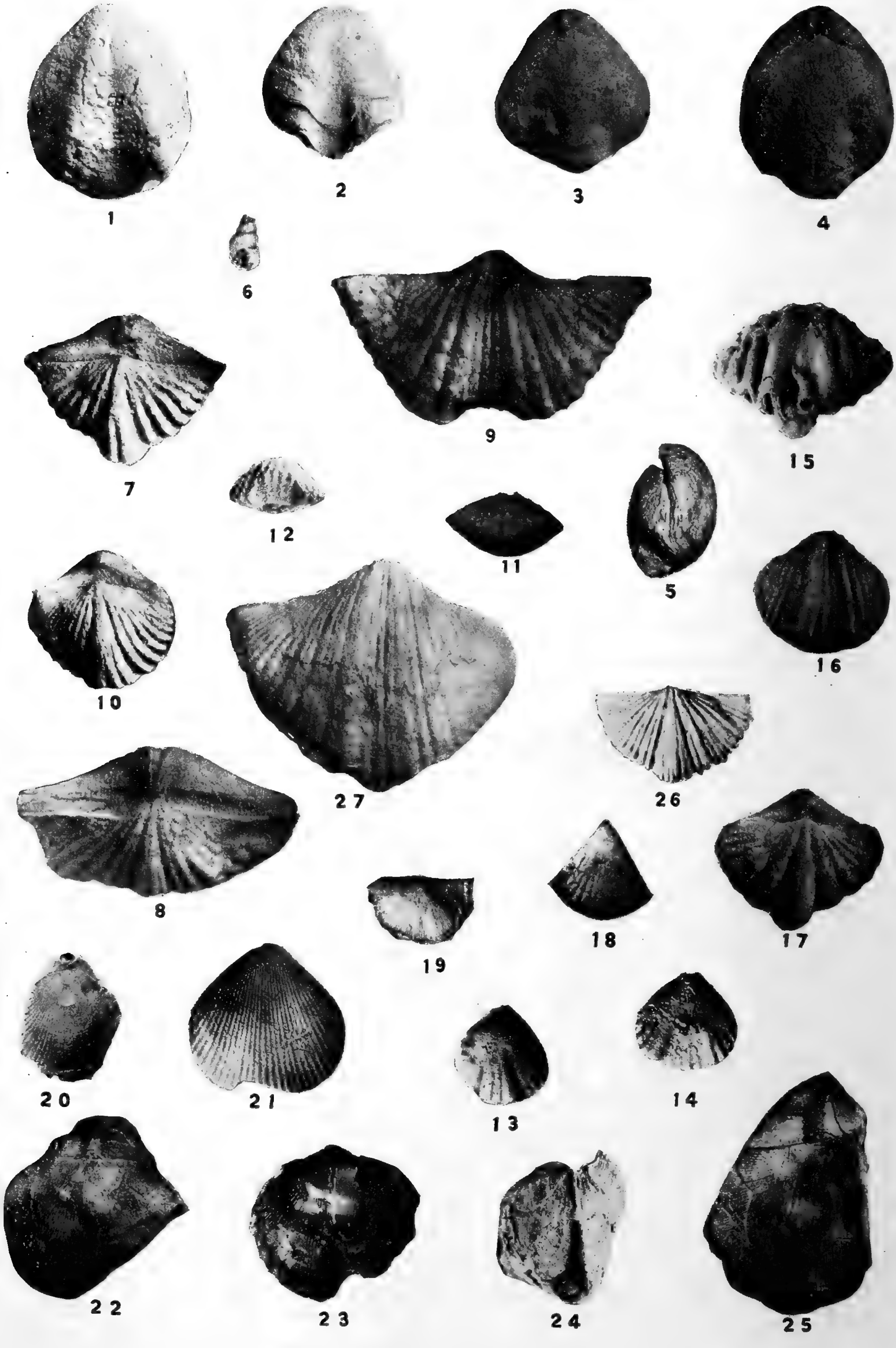
PHILLIPSIA sp.?

Plate 19, figure 16

Several specimens of *Phillipsia* were collected, but most of them were lost during transportation. The ones in the collection are too imperfect for specific reference.

From all collections made from the Amsden the number of specimens of each species listed below were selected as worthy of placing in our cabinets. These numbers furnish a rough approximation of relative abundance.

Orbiculoidea	3
Orthotetes	37
Meekella	3
Chonetes	1
Productus phillipsi	48
Pustula	1
Schizophoria	2
Pugnoides	20
Tetracamera	2
Spiriferina	25
Spirifer welleri	80
Spirifer pellænsis	51
Spirifer shoshonensis	4
Martinia	1
Eumetria	7
Cleiothyris	5
Composita	314
Ortonia	1
Microdon	1
Myalina	7
Bulimorpha	4
Bucanopsis	3
Loxonema	4
Phillipsia	1
Zaphrentis	54
Chætetes	54
Paleonilo	29
Orthoceras	2
Cycloceras	1



FOSSILS FROM THE AMSDEN FORMATION

Explanation of Plates

Plate 18.—*Fossils from the Amsden Formation*

Composita trinuclea (Hall)
Figures 1 and 2. Pedicle valves of two average individuals.
Figures 3 and 4. Brachial views of conjoined valves of average individuals.
Figure 5. Side view of an average specimen.

Loxonema wortheni Weller
Figure 6. View of an imperfect specimen (×2).

Spirifer pellænsis Weller
Figure 7. Brachial view of conjoined valves of an average specimen.
Figure 8. Posterior view of a long hinge-lined specimen.
Figure 9. Exterior of a pedicle valve of a long hinge-lined specimen.

Spirifer welleri n. sp.
Figure 10. Brachial view of conjoined valves.
Figure 11. Front view of a small specimen.
Figure 16. Exterior view of a pedicle valve (×¾).

Pugnoides ottumwa (White)
Figure 12. Front view of an average specimen.
Figures 13 and 14. Brachial and pedicle views of the same specimen.

Ortonia cf. *blatchleyi* C. and B.
Figure 15. Specimen in sinus of *Spiriferina browni.*

Spiriferina browni n. sp.
Figure 15. Front view of an average specimen.
Figure 17. Brachial view of an average specimen.

Tetracamera subcuneata (Hall)
Figure 18. Exterior of pedicle valve.

Chonetes chesterensis Weller
Figure 19. Exterior of a pedicle valve.

Eumetria verneuiliana Hall
Figure 20. Brachial view of conjoined valves of a small, imperfect specimen.
Figure 21. Pedicle view of a larger specimen.

Meekella amsdenensis n. sp.
Figure 22. Brachial view of conjoined valves of an imperfect specimen.
Figure 23. Pedicle view cut to show septal plates.
Figure 24. Side view of a perfect specimen.
Figure 25. Branchial view of conjoined valves of an imperfect specimen.

Spirifer shoshonensis n. sp.
Figure 26. Exterior of brachial valve of a small specimen.
Figure 27. Exterior of a pedicle valve of a large specimen.

PLATE 19.—*Fossils from the Amsden Formation*

Pustula genevievensis (Weller)

FIGURES 1–2. Ventral and side views of a pedicle valve.

Orthotetes kaskaskiensis (McChesney)

FIGURE 3. Posterior view of an imperfect specimen.

FIGURE 4. Exterior view of a brachial valve.

Diaphragmus phillipsi (Norwood and Pratten)

FIGURES 5–6. Brachial and pedicle valves.

Orbiculoidea wyomingensis n. sp.

FIGURES 7–8. Pedicle and brachial valves of imperfect specimens.

Bucanopsis or *Bellerophon*

FIGURES 9–10. Two views of an interior cast.

Microdon cf. *oblongus* (Hall)

FIGURE 11. Internal cast of a specimen referred to this species with some doubt.

FIGURE 25. Specimen doubtfully referred to this species.

Schizophoria swallovi Hall

FIGURES 12–13. Anterior and pedicle views of an immature specimen.

Cleiothyridina hirsuta (Hall)

FIGURE 14. Brachial view of conjoined valves of a perfect specimen.

Bulimorpha canaliculata Hall

FIGURE 15. Side view of a specimen with the apical coil missing.

Phillipsia sp.?

FIGURE 16. Dorsal view of an imperfect pygidium.

Martinia n. sp.

FIGURES 17–18. Brachial and lateral views of conjoined valves of a perfect specimen.

Zaphrentis amsdenensis n. sp.

FIGURE 19. Side view of a specimen of average size.

FIGURE 20. View of the calyx (×2).

Chætetes?

FIGURES 21–22. Two views of a silicified specimen.

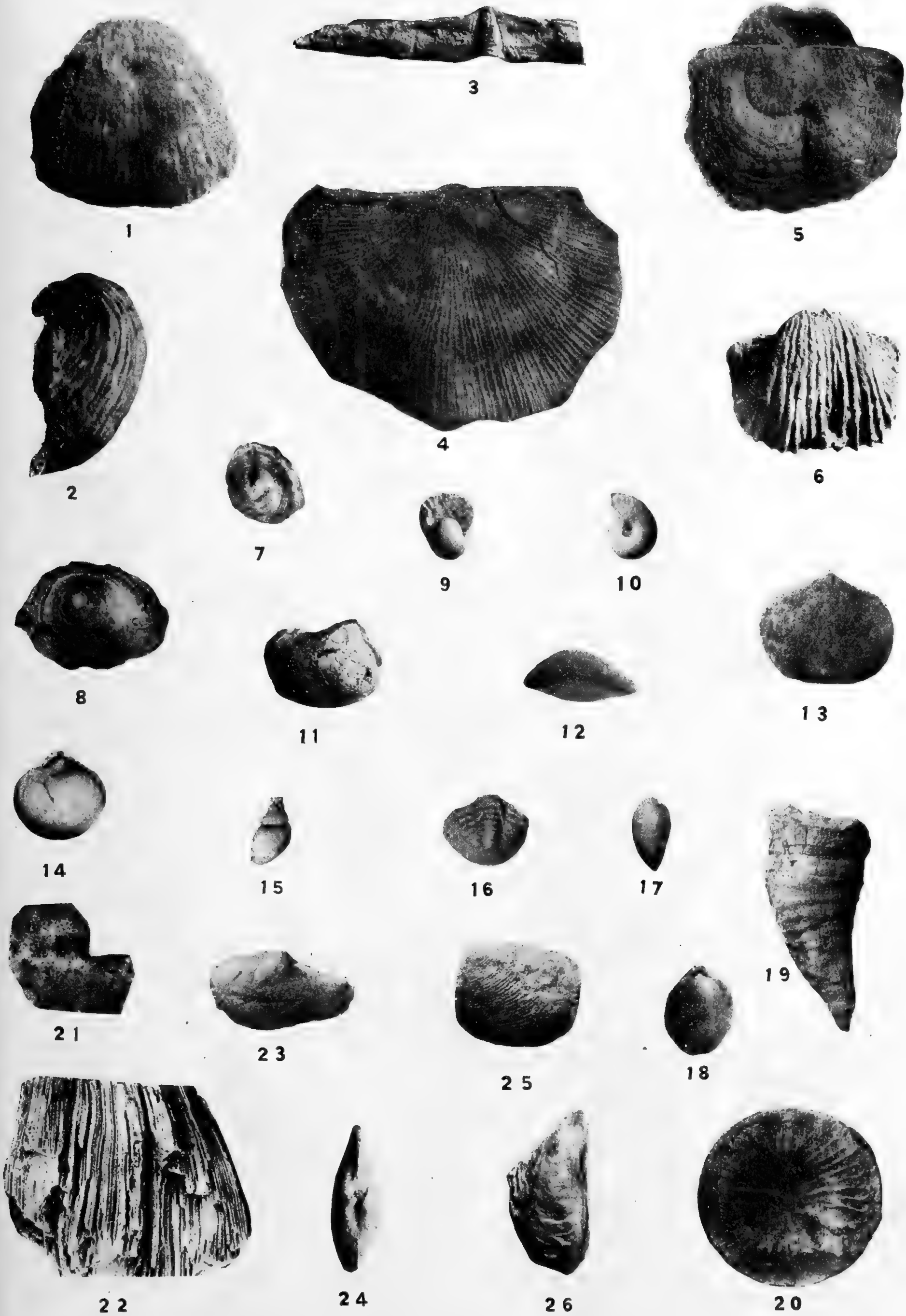
Paleoneilo amsdenensis n. sp.

FIGURE 23. Lateral view of a nearly perfect internal mould.

FIGURE 24. Dorsal view of the same specimen.

Myalina sancti-ludovici Worthen

FIGURE 26. Lateral view of a perfect specimen.



FOSSILS FROM THE AMSDEN FORMATION

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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STRATIGRAPHY OF THE NEW YORK CLINTON[1]

BY GEORGE H. CHADWICK

(Presented before the Society December 28, 1917)

CONTENTS

[1] Manuscript received by the Secretary of the Society December 28, 1917.

Historical Introduction

The "Clinton group" of western New York has been supposedly a well known formation. Hall (2)[2], in 1843, described the section on the Genesee River at Rochester, whose various subdivisions of shale and limestone he believed he had correctly traced eastward to the limit of his district (namely, Red Creek), and he affirmed the stratigraphic equivalence of five of these to the series of sandy shales at Clinton, in central New York, described in the preceding year by his colleague on the Survey, Vanuxem (1). Hall also followed the same group of strata westward to the Niagara River, where he correctly noted that the "Clinton" portion had diminished in thickness by the nearly total loss of its shale members, thus becoming a continuous massive limestone.

It should be recalled that two of the sections just mentioned, namely, the Genesee gorge at Rochester and the Niagara gorge above Lewiston, are the only complete exposures of the group in New York State (9: 9-10), and that it would be difficult, if not impossible, to find any errors in Hall's work from a surface examination alone. No criticism can therefore be made of his work or of those who have builded on it, though his correlations are now found to be partly in error.

The section of the so-called Clinton at Rochester, long taken as the standard for comparison with other regions, is given below, together with the names used by Hall (3), those applied by Hartnagel (8) in 1907 on the basis of Hall's correlations, and the revised names, the necessity for which is brought out in the sequel. This section now proves to be far from a complete section of the New York Clinton, since several important members are entirely missing. It is as follows, every inch being accessible:

[2] The numbers in parenthesis refer to the list of works at the end of this paper.

(Rochester shale conformably overlies)

Hall's names, 1843.	*Section.*	*Hartnagel, 1907.*	*This paper.*
Upper (Clinton) limestone	Crystalline limestone... 7′ Limestone and shale.... 11′	Irondequoit limestone	Irondequoit (and Phœnix)
Second green shale	Graptolite shale........ 6′ Purple shale with "pearly layers" .... 18′	Williamson shale	Williamson Sodus (true)
Pentamerus limestone	Limestone .... 14′	Wolcott limestone	Reynales
Oolitic iron ore	Hematite ore .... 1′	Furnaceville	Furnaceville
Lower green shale	Shale with limestone.... 3′ Green shale .... 21′	Sodus shale	Bear Creek Maplewood

(Thorold gray sandstone conformably underlies)

The reason for the changes here made might never have appeared from a study of the outcrops alone. But fortunately Hartnagel, returning to the attack, conducted for the State a series of drillings for iron ore in the drift-covered Clinton belt (9:10) of central New York which revealed some totally unexpected relations. The results of this investigation were briefly stated in 1908 in a paper (9) by Newland and Hartnagel, of an economic nature, in which intimation was given of a fuller report to come on the paleontologic and stratigraphic data secured; this expected sequel, however, has not yet appeared.

Meantime, because of the burial of Hartnagel's results in a report ostensibly economic, their revolutionary character has been generally missed, as an inspection of the later papers cited will show. It is proposed, therefore, to epitomize the published information on our Clinton strata, with the aid of the charts (figures 1 and 2) of the sections and well records, and to make those changes in the nomenclature which have been rendered necessary.

To Newland and Hartnagel belong the chief credit for the field observations employed in this revision. Their careful records of the diamond-drill cores for eight judiciously placed test holes, besides much other data assembled by them, will always be of inestimable service to all workers. An extensive series of rocks presented to the University of Rochester by

the early New York survey from the localities described in their reports (1, 2) has been of much assistance.

The cooperation of one of our students, Miss Flora Crombie, and aid received from Mr. Ira Edwards, now of the Milwaukee Museum, and from Prof. W. J. Miller are gratefully acknowledged. Since the preparation of the manuscript very kind criticism and suggestions have been received from Doctors M. Y. Williams, E. M. Kindle, and C. K. Swartz, and especially from the censor of the paper, Professor Schuchert.

Comparison of western Sections

The sections will be considered in order from west to east, beginning at Rochester. The horizontal datum line in the charts is the base of the Rochester shale. The Rochester section of the "Clinton" has just been summarized and will be found drawn to scale at the left end of figure 1. It consists, in the old interpretation, of two limestones and two shales, with an iron-ore bed. The next continuous section is that of the test hole at Wallington, near Sodus. In this there are, however, *three* limestones and three shales, with the same bed of iron ore. The new limestone member is found to come in between the dark graptolitic portion of the upper shale at Rochester and the purplish shale portion with its "pearly layers." Both of these two upper shale members have gained considerably in thickness, whereas the bottom shale and also the upper limestone have apparently diminished. It is evident on closer consideration, however, that it is the lower shaly portion of the upper limestone at Rochester which in this well has become the topmost 20 feet of shale—a shale said to be similar to the Rochester shale and highly fossiliferous. But the graptolite shale itself has also expanded to 15 feet. At the base of the section the Thorold sandstone appears to be missing, so that the attenuated basal "Clinton" shale rests directly on the variegated Medina shale.

With but minor variations, the relations shown in the Wallington well continue eastward to the Oswego River. All the limestone members, it should be observed, become increasingly shaly, while the shale members (except the basal shale) continue to thicken and several new ore seams make their appearance.

Two of these new ore horizons occur first in the section next east of Wallington, that of the test hole at Wolcott. Here an important ore comes in just above the middle limestone. This ore outcrops at the old furnace north of Wolcott and at a few other points to the west. Another new but thin ore bed appears at the top of the lower limestone (here mostly shale) and is exposed in the diggings at Sterling Station, a few

miles east, where it is 8 feet above their main ore bed (9:57). In the well at South Granby a fourth thin ore and limestone are inserted between the graptolitic shale and those shaly members above which seem to represent shale replacements of much of the upper limestone of the Rochester section. Meantime the lowest ore bed, so persistent from the Rochester meridian, has abruptly disappeared (9:35) between Red Creek and Martville (compare text-figure 4).

Now the exceedingly interesting point brought out by Hartnagel (9: 21, 22) is that in the absence of good continuous exposures the middle limestone of the Wolcott region was confused with the lower limestone at Rochester, both of them carrying *Pentamerus oblongus* abundantly at their respective localities; and in consequence the middle shale at Sodus, with its pearly layers and purple color, was forcibly connected with the bright green barren basal shale of Rochester. It will be seen that the latter is nearly or quite missing on the meridians of Sodus and Wolcott, while its overlying limestone has become so shaly as to seldom outcrop. In the typical Sodus section, that of the old Shaker settlement on Second Creek, this lower limestone with its ore bed is beneath the waters of Sodus Bay. The long list of fossils described by Hall from the "lower shale at Sodus" are all forms of the middle or purple shale, which must accordingly take the name of Sodus shale, and whose place is in the lower part of the "upper shale" at Rochester. Similarly the only limestone with Pentamerus at or near Wolcott is the middle limestone, which is absent from the Rochester section, and this must retain the name Wolcott limestone, while both the lower limestone and the basal shale at Rochester remain yet to be named. The necessity for these changes is discussed again beyond.

A glance at the chart shows how easy it was for this confusion to arise. Had we not the intervening section at Ontario, with its thinned basal shale and absence of the Thorold, we might readily ignore the incisive evidence of the fossils and repeat Hall's error, which was the more excusable since a shale seeming to occupy the position of our basal green shale carries the Sodus Cœlospiras at Niagara. This Niagara section is accordingly also given on the chart, together with two others to the west as reported by Schuchert (12:308-311), in order to show that the "Clinton basal shale" at Niagara is not the barren green basal shale of Rochester; for, according to Logan (Geology of Canada, 313)[3], the latter reappears in the next section west of Niagara and there carries the Medina worm burrow, Arthrophycus. These relations, as understood by Schuchert, are shown in the diagram, which thus clearly brings out a discon-

[3] Footnote 3 is on page 334.

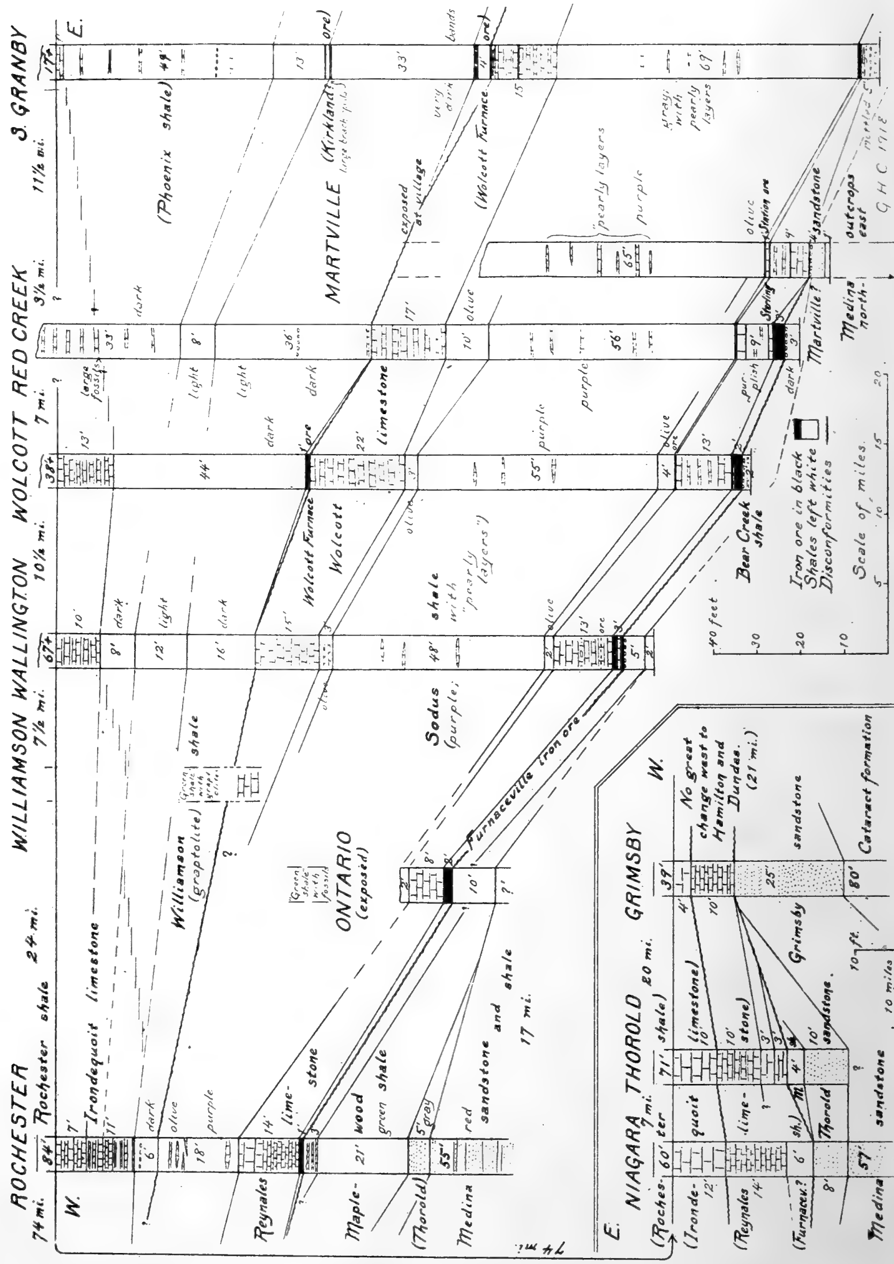

FIGURE 1.—*Correlation of Clinton Strata between Genesee and Oswego Rivers*
(Shales left white in the columnar sections)

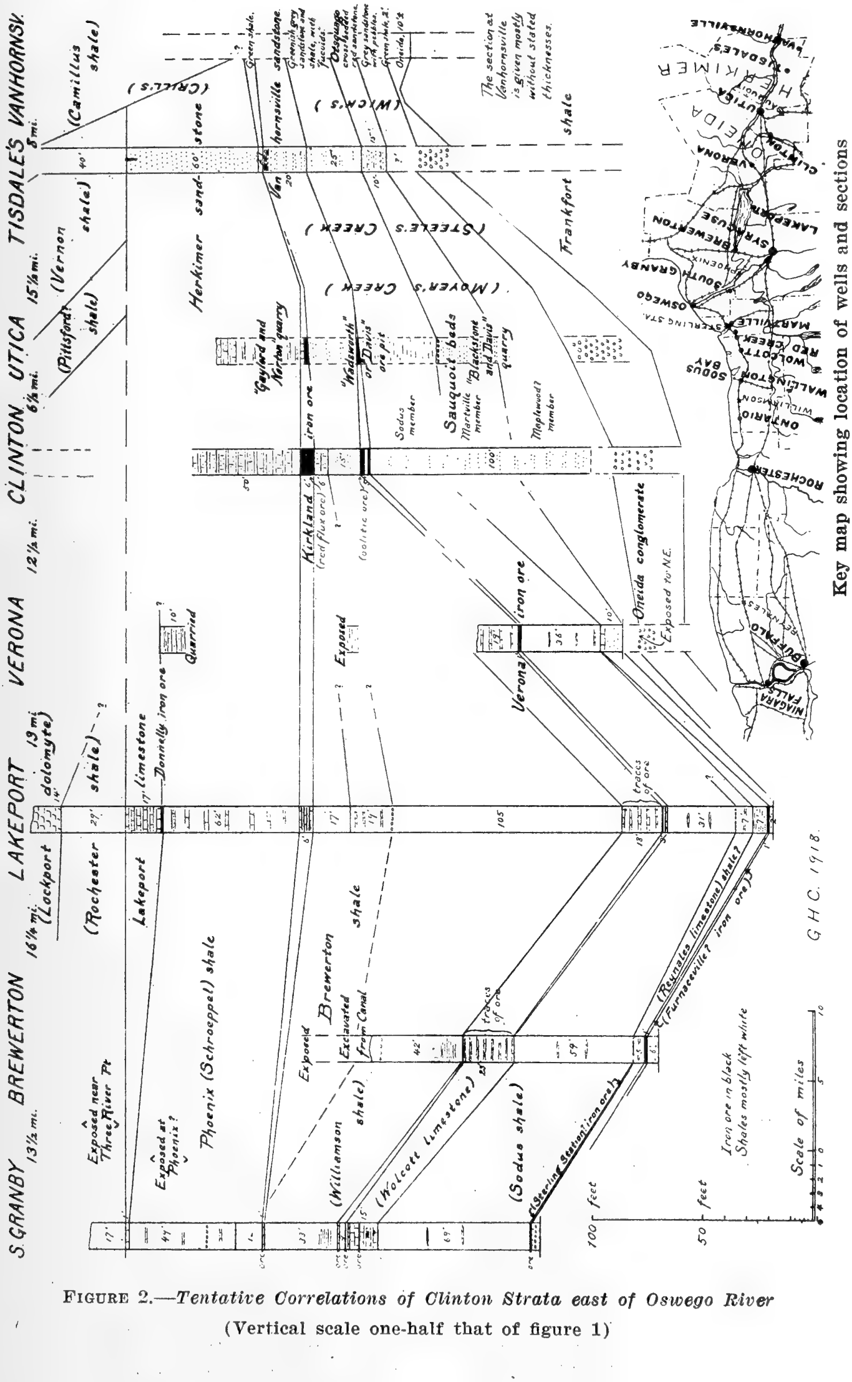

FIGURE 2.—*Tentative Correlations of Clinton Strata east of Oswego River*
(Vertical scale one-half that of figure 1)

formable contact of the marine Clinton beds on those beneath.[3] The barren green shale at Rochester belongs, therefore, *below* this disconformity and with the Thorold sandstone. Though the line between these is "sharp," in the sense of there being no extended gradation, they plainly blend into a single group at Rochester.

Correlations Eastward

It was originally intended to end this paper at the Oswego River, in the belief that the stratigraphy to the east was too complicated or obscure to be solved with present data. But an intensive study of the eastern sections dispels so much of their obscurity that a second portion of the chart (figure 2) has been prepared to illustrate how the correlations can be (*very tentatively*) carried eastward, even to the limit of outcrop of this group in New York, and thus a groundwork of hypothesis laid for future field study of these eastern sections.

In this portion of the chart the greater thickness of the Clinton has compelled a smaller vertical scale, and it has also been necessary to show the formations above the Rochester shale, since the Rochester soon ceases to appear in the more easterly sections. In its absence the line of unconformity at the summit of the Clinton is taken as the datum until this line begins to bevel sharply down across the Clinton strata.

The chart recommences with the South Granby well section, which is repeated on this plate. The next section, an incomplete one, is at Brewerton, which lies at about the middle of the width of the Clinton belt and therefore presumably midway between base and summit. The records of the Syracuse wells (9:24-25; 11:8), located on the same meridian, since the combined Rochester and Lockport can here scarcely exceed 200 feet, would indicate a minimum of 225 to 230 feet of Clinton strata here-

[3] This appears to be an error. According to Dr. M. Y. Williams (private communication), Logan's account was based on that of Alexander Murray in the First Annual Report of the Canadian Survey (1843), p. 75. Both accounts give 10 feet of the gray (Thorold) sandstone overlaid by 4 feet of a "bluish-green argillaceous shale" containing Arthrophycus, especially near its contact with the sandstone, and followed in turn by 6 feet of calcareous beds before the Pentamerus layer is reached. Neither Doctor Williams nor Doctor Kindle find any trace of this shale in the exposures seen by them or in the records of the Welland Canal engineers. Doctor Kindle's field notes (transcript kindly furnished the writer) show the Pentamerus layer resting directly on but 8 feet of Thorold sandstone. Although this section was clearly made at a different point from Murray's, the discrepancy (of 12 feet of strata) seems too great to be accounted for even by the known disconformity.

There may be a question as to the identity of the "gray band" at Rochester with the Thorold sandstone. According to Hall (Annual Report for 1837, p. 297), the stratigraphic continuity is interrupted in the Lockport region. Observers agree that the true Thorold is closely linked to the subjacent red beds, whereas the converse is true of the gray sandstone at Rochester. This matter requires investigation.

abouts. The vertical allocation of this partial section on the chart has been guided by these two criteria quite as much as by the evident link that it furnishes between the lower portions of the South Granby and Lakeport columns. The fossiliferous olive shales at Brewerton, although their few fossils are largely Rochester shale species (11: 58), are thus found to be far down in the Clinton, below the base of the true Rochester shale. The latter, however, is exposed (judging by character, fossils, and contiguity to Lockport outcrops) a couple of miles northeast of Three River Point (11: 58), while the olive shale at Phœnix (loc. cit.), near by, can be but a little lower in the sequence, though characteristically Clinton.

Most important of all the drillings is that at Lakeport, which commences in the Lockport and terminates in apparently the Oneida, though possibly a bit higher. Besides giving a maximum measure[4] of the New York Clinton, and seeming to confirm the position of the shales at Brewerton in the highly fossiliferous zones penetrated about midway of the well (135 to 171 feet depth), this bore hole adds two new ore horizons and completes the list of known subdivisions in the Clinton group of New York State. Before continuing eastward (it is but 25 miles to Clinton) it will be well to summarize these subdivisions with their thicknesses at Lakeport and the names presently to be formally proposed for them. From the top downward they are:

Name used in this paper.	Thickness in Lakeport well.	Comments.
Lockport dolomite (undivided)	14 feet shown	Probably at least 100′.
Gates limestone	Absent (hiatus)	20 feet at Rochester.
Rochester shale	29 feet	Upper half missing (?).
Lakeport limestone	16 feet	Considerable shale.
Donnelly iron ore	1 foot	In limestone.
Phœnix (Schrœppel) shale	62 feet	With calc. sandstone.
Kirkland limestone and ore	6 feet	Highly crinoidal.
Brewerton shale	36 feet	With many fossils.
Williamson shale	105 feet	Dark shale in part.
Wolcott Furnace iron ore	Absent (hiatus?)	See Wolcott section.
Wolcott limestone	18 feet	Here mostly shale.
Verona iron ore	3 feet	Important to east.
Sodus shale with lime lentils	31 feet	Purplish to west.
Sterling Station iron ore	Trace only	See note below.
Reynales limestone	7 feet	Here mostly shale.
Unnamed dark shale	7 feet	Part of Reynales?
Furnaceville iron ore[5]	1 foot	See note below.

[4] Somewhat exceeded in the Chittenango well a few miles south.

[5] The identification of the basal ore bed here and at Brewerton as a reappearance of the Furnaceville instead of an extension of the Sterling Station ore may be erroneous, but it involves us in fewer difficulties to find the latter in the "trace of ore" occurring at the proper interval above this one. Text-figure 4 shows how easy a different correlation would be, though the black pebble zone supports that here made.

Bear Creek shale...............	4 inches?........	See discussion beyond.
Martville? (Otsquago?) sandstone	2 feet?..........	Somewhat reddish color.
Maplewood shale...............	Absent (hiatus)...	21 feet at Rochester.
Oneida conglomerate*...........	Entered? (6″).....	"White sandstone."

(* In the western sections the Thorold sandstone occupies a similar position beneath the Maplewood green shale.)

Too much emphasis can not be placed on the significance, for purposes of classification, of the hiatuses in this, the thickest Clinton section in New York. They accord with gaps already recognized in the previous sections.

Special attention should be called to the presence here, but with greatly reduced thickness, of the Rochester shale, 20 miles to the east of its last known outcrop and apparently without noteworthy change in character. These facts point to its total extinction within a few miles to the eastward. But beneath this shale, separated from it by a limestone that Hartnagel clearly considered the top of the Clinton (see 9:25) is the 60-foot shale mass carrying the first of the economically important sandstone intercalations of the Clinton that occur in outcrop at several points along the south side of Oneida Lake east and west of this well (1:89), becoming of increasing importance eastward (1:87). This mass we believe to be identical with the shale division seen at Phœnix (11:57-58), with its large element of Rochester shale fossils. In the six feet of crinoidal ore-bearing limestone below these 60 feet of beds we recognize the first definite presence of the upper (fossil or "red flux") ore of the Clinton district, while in the thin ore above them we see, with Vanuxem (1:88), the equivalent not only of Donnelly's ore (9:26), but also of that over Tipple's quarry, near Verona (1:87-88).

For the Verona region Professor Fairchild's field copy of the topographic map with his memoranda of outcrops has aided greatly. The vertical adjustment of the partial well section and the important exposures have been arrived at by computations of altitude and dip that would be wearisome here, but which seemed to clear away the problems of correlation between Lakeport and Clinton as soon as they were plotted on the chart. The limestone members are now all shale, identifiable only by their attendant ore bodies; but Vanuxem's correlation of the layers above the Verona ore bed with those exposed in the village of Martville and "in contact with the ore at Wolcott furnace" (1:87) on the basis of the guide fossil *"Retepora clintoni"* (Hall's *"Fenestella prisca?"*) is amply confirmed by the stratigraphy. So also is Hartnagel's seemingly contradictory assertion (9:26) that the Verona fossil ore "occupies the same relative horizon in the formation as the Clinton oolitic bed." In

our belief they are identical. Their apparent difference in character will be explained later.

If the Kirkland ("red flux") limestone carries no more ore around Verona than in the Lakeport well, it is not surprising that its horizon has failed of recognition in the outcrop. The seam alluded to by Hartnagel (9 : 26) as found in excavations in Verona village—probably the same as that mentioned by Vanuxem (1 : 87)—is not likely to lie more than 20 feet above the Verona ore (if it is not indeed that bed itself), and so just barely above the horizon at which the drill entered the rock or in the place of the Wolcott Furnace bed. It can not be the red-flux bed.

Great interest attaches to the lower part of the Verona well record. The proximity (on the north) of the type exposure of the Oneida conglomerate indicates that the drill must have stopped within a few feet of that rock. In the absence of the lower ore layers, it becomes impossible to recognize the Reynales horizon in the record as given, though the thicknesses would suggest that it is still present above the lower 10 feet of sandy beds. These sandstones mark, therefore, the inception of that great basal expansion which impresses one in the Clinton region (9 : 26). It will soon be shown that they are approximately Martville.

The Type Section

The literature on the remaining sections is far from satisfactory, the measurements being largely estimates, often between rather wide limits, while almost no measurements whatever are reported east of Tisdale's mill, but merely the order of succession. Yet on piecing together the available data one gets a more complete concept of the stratigraphy than (in default of measurements) can be shown on the chart. At Clinton village we have at the top (excluding whatever may lie in the concealed interval just above) the mass of calcareous sandstone and thin shale partings which is clearly our Phœnix division growing more sandy toward the shoreline. Its thickness is given as 50 feet plus, with an unmeasured gap between it and the Lockport, the Rochester not being seen. These Phœnix sandy shales, with their prenuncial Rochester fauna, contain the explanation for the rather reasonable belief (9 : 19, 27; 10 : 7) that the Rochester shale horizon is embraced in the type Clinton section. Further evidence to the contrary will be recited farther on.

Next below the Phœnix beds is the calcareous "red-flux" ore, 6 feet thick. Even within sight of Clinton village (1 : 86) this ore is known to pass westward into an ore-bearing limestone with crinoids, and its identification with the ore-bearing limestone beneath the upper shale in the

Lakeport Clinton series is certain. Its extension eastward in a long row of outcrops on the steep south wall of the Mohawk Valley is also beyond question. The interesting thing is to see it change from a calcareous fossil ore at Clinton to a siliceous oolitic ore at Steeles Creek (1:82), and then into a highly ferruginous sand (see Vanhornsville sandstone later). On inspection we find that the Furnaceville ore (if correctly identified east of Martville) undergoes a similar change to an oolitic ore in passing eastward from Rochester, and we are now prepared to assert that the Verona fossil ore is likewise converted into the oolitic or lower ore bed of Clinton.[6] This is indicated by the rate at which this ore has been rising in the diagram from Lakeport to Verona, and is corroborated by the presence throughout the underlying 35 to 40 feet of shale (1:84) of the fossil *Beyrichia lata* (Vanuxem's "broad Agnostis," 1:83, 84)—a form very characteristic of the true Sodus shale and its "pearly layers" as well. Below this shale, with a suggestion of disconformity that did not escape Vanuxem's eye (1:83), are the sandstone quarries of Blackstone and Davis, south of Utica, with their remarkable "fucoids." Somewhere in this mass Hall reports *Pyrenomœus cuneatus* (3:87) of the Bear Creek fauna, indicating the Martville age of these sandstones. The red coloring in some of the upper layers (1:82) helps to place their horizon in the sections farther east, and also ties them to the supposed Martville of the Lakeport well (compare text-figure 4). The strata beneath become more shaly again, and it is wholly possible that they signify a return of the basal or Maplewood shale of the Rochester section—a suggestion that is heightened by their holding a similar conformable relation to the Oneida sandstone and conglomerate below them as the Maplewood does to the Thorold.

Although we can thus pick out rather confidently the presence of certain members in these 100 feet of lower beds at Clinton, their exact discrimination, with discovery of the fate of the Reynales and other members, awaits patient field-work. It is desirable meanwhile to have a term for the whole mass from the oolitic ore to the Oneida, and the name Sauquoit is therefore employed on the chart and defined beyond.

As to the 21 feet of strata between the two ore beds, and which are open to easy study in the old workings at Clinton, the fossils will undoubtedly decide what horizons have been compressed into this small span, which probably contains at least one important hiatus (see page 359). From the intercalations of ferriferous limestone in the 20 feet (15

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[6] **Doctor Swartz writes: "I find it difficult to believe that the Verona iron ore is correctly identified with the Oolitic ore at Clinton. It seems to me not impossible that it is a lower bed which corresponds in position with a heavy bed of iron ore in Maryland."**

at Clinton) of blue shale next above the oolitic bed at Lairdsville (1:87), it is a safe hazard that the Wolcott is still included, but whether forming the whole shale mass or only the lower few feet up to the thin middle ore found on Stebbins Creek (1:85) is uncertain; and whether the calcareous sandstone below the red-flux ore is Williamson or Brewerton can be only conjectured, though the rumor of "guide Clinton graptolites" somewhere in the upper beds (10:7, footnote) is reminiscent of the former.[7]

The Shoreward Region

The section given by Hall (3:16) in the quarries on the hill south of Utica and the better one on Swift Creek, near by, described by Vanuxem (1:84-85), are fundamental, though because of certain unmeasured intervals they appear but imperfectly on the chart. Beyond these comes Steeles Creek, south of Ilion, and then the place Hall calls Tisdale's mill, at both of which (1:82, 81; 3:16) is a resistant sandstone, 60 to 70 feet thick, known as the "upper gray band," forming the summit of the Clinton. In the largely unique and mostly molluscan fauna of this mass *Trimerus delphinocephalus* is the only definitely Rochester element, whereas two of the other eight or ten species (3:100-105) are common to the Brassfield of Ohio (13:1484, 1487-1488). But Vanuxem says (1:82) that Trimerus begins in the iron ores, and Hall (3:299) also reports it far down in the Clinton. This sandstone continues unabated west toward Moyers ("Myers," 1:257) Creek, then suddenly drops out of the sections. Five or six miles west of Moyers Creek, at Utica, the equally thick mass of the Phœnix shales (here mostly sandstone) is at the Clinton summit in the same relative position and carrying fucoids, as does the gray band at Wick's store east of Tisdale's (1:81), where it also includes shale. Were the "gray band" still present as a distinct member above the Phœnix beds, it could scarcely fail to outcrop in the excellent section on Swift Creek, and the conclusion is therefore drawn that this heavy white stratum, which for convenience we will call the Herkimer sandstone, is the strand facies of the Phœnix (Schrœppel) shale, and so of some part of the lower Irondequoit limestone of the Rochester section, rather than, as has been claimed, of the much attenuated Rochester shale of the Lakeport well. We will recur to this question beyond.

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[7] A different interpretation has been adopted in text-figure 3, where the 6 feet of sandstone is identified as Brewerton and the underlying 15 feet of shale is all referred to the Wolcott, the Williamson being shown as lapped out. This is the relation suggested by the physical history as discussed beyond.

The rest of the Tisdale section (9 : 27; 3 : 16) appears simple. Under the gray band are two feet of shale (which may be a misprint, since Hall (3 : 16) gives "thickness?"), then "red sandstone with a sparkling grain" (1 : 81), together with gray sandstone, shale, and iron ore, about 20 feet. Since the upper ore bed is known to come as far east as Steeles Creek (1 : 82) or within five miles, meantime becoming oolitic, there seems no reason for not treating these beds as the middle ore-bearing portion of the Clinton region (see 9 : 42). The coarse, friable mixture of sand and hematite (9 : 47) at this level becomes more marked (1 : 80-81) at Vanhornsville (spelled "Vanhornesville" on the topographic map and in 9 : 28), near the eastern limit of the group, but just how much it represents of the Verona-Kirkland span at Clinton is unknown. The three lower strata are clearly the Sauquoit beds in their triple aspect, the middle sandstone being the beds of the Blackstone quarry here become heavily cross-bedded (1 : 82), and thus passing eastward into the cross-bedded red laminated sandstone of the Otsquago Creek below Vanhornsville (1 : 80, 81; 9 : 28), which may just possibly become the "coarse (red 3 : 15) sandstone with much iron ore" next below the Camillus shale at Salt Springville (9 : 28), the last Clinton exposure, though this sounds more like the Vanhornsville bed.

The Oneida conglomerate lies beneath in all these localities (1 : 80-82; 3 : 15-16; 9 : 27-28), but from its erratic thinning and rethickening it appears likely that some portion of the basal Clinton shale may be merged with it at the east. It must not be forgotten that Vanuxem (1 : 75) considered the Oneida "a part of the Clinton group," separated, he says, for convenience. We would reverse this statement and consider the unfossiliferous part of the basal shale below the Otsquago-Martville as a part of the Oneida in its broader application, including, it would seem, the Thorold and Maplewood of western New York, but not any part of the true red Medina. The belief that Upper Medina strata existed in these eastern sections above the Oneida conglomerate (see 7 : plate 2, and Science, new series, volume 28 (1908) : 347) undoubtedly grew out of the presence here of the cross-bedded and normally red Otsquago sandstone; but as the red color of this fades away westward, while the Medina darkens in coming east, they grow more and more unlike as they approach the common meeting-point, and so can have little in common. The evidence in hand favors the conclusion of Vanuxem (1 : 75-78) and Hartnagel (7 : 36) that the Oneida is "never far below the base of the Clinton" and is closely connected with its basal shale.

Horizons and Fossils

GENERAL OBSERVATIONS

The subdivisional names used in this paper will now be defined and their best known fossils listed, beginning with the basal shales. The Thorold and Oneida need no redescription. The lists of fossils are preliminary, compiled chiefly from Hall (3) and admittedly incomplete, but they may be useful. In some instances the fossils have furnished gratifying confirmation of the correlation based on the stratigraphy, and in no case have they conflicted with it. But the stratigraphy has always been the main guide.

MAPLEWOOD SHALE

The maximum exposure is in the Genesee gorge at Maplewood Park, Rochester, where 21 feet of fine-grained, unctuous, bright-green, non-fossiliferous shale of uniform texture rest on the Thorold sandstone. This is Hall's "lower green shale" and Hartnagel's "Sodus" (8 : 13), exclusive of the uppermost three feet. This shale probably terminates eastward without reaching Sodus, the true Sodus shale being a higher member. The stratigraphic relations of the Maplewood are with the beds below rather than above it. So far as now known to the writer, its only fossil is the *Arthrophycus alleghaniense,* reported by Schuchert (following Logan, Geology of Canada, page 313) at Thorold (12 : 310) in a green shale of similar position.[8] The fossils sometimes quoted from this horizon appear all to come from the Bear Creek or other higher division.

SAUQUOIT BEDS

This name is temporarily extended over all the shale and sandstone beds between the Oneida conglomerate and the oolitic ore bed in the Oriskany and Sauquoit valleys, about 100 feet thick, with the type section on Swift Creek, north of Sauquoit village (1 : 84) and in its vicinity. It may be desirable later to restrict the term to some definite unit within this series, in which are probably present Sodus, Martville, and perhaps Maplewood and other horizons. The fossils are:

Aristophycus? cf. *heterophyllum*
Buthotrephis gracilis
Buthotrephis gracilis intermedia
Chondrites? ramosus (3:21)
Palæophycus sp.? (3 :22, Pl. 8, f. 3)
Rusophycus clavatum
Rusophycus subangulatum
Rusophycus pudicum (*biloba* 1:83)
Asterophycus? palmatum (3:20, Pl. 6)
Blastophycus? impudicum (3:20)
Arthraria dicephala, nom. nov.
Dactylophycus? sp. (3 : Pl. 8, f.5)

[8] See preceding footnote 3, p. 334.

Dactylophycus pes-avis, nom. nov.	*Leptodesma rhomboidea*
Ichnophycus tridactylus	*Pyrenomœus cuneatus*
Conostichus? medusa, nom. nov.	*Bucanella trilobata*
Conostichus? polygonatus, nom nov.	*Beyrichia lata*
Camarotœchia æquiradiata	*Bollia lata* (?)
Pterinea emacerata	Tracks and trails (3:27–29)

MARTVILLE SANDSTONE

The type locality is Bentley's quarry (1: 89, 78, 74), intermediate between Martville and Hannibal (the latter name is preoccupied in stratigraphy), where about 10 feet of thin grayish green sandstone and shale, with fossils, are seen at the top of the quarry resting with a shale contact on the four or five feet of light gray or slightly mottled sandstone considered Oneida (or Thorold) by Vanuxem, below which is the red Medina sandstone. The Martville is uppermost of these three sandstones and carries—[9]

"Numerous fucoids and other forms" (compare the preceding list).

Lingula clintoni (*L. oblonga* Conrad), "besides some other fossils" (1: 89).

Probably also *Dolichopterus? prominens* (Paleontology of New York, volume 7, page 157; Memoir 14, page 200).

This stratum appears to be only three or four feet thick in the Martville well, where it lies beneath the horizon of the Furnaceville ore with an intervening breccia, the ore being absent and the Reynales limestone succeeding. Though similar conditions exist in the Verona well, whence the sandstone extends eastward through the Blackstone quarry and eventually merges into or is supplanted by the red Otsquago sandstone, yet in the territory adjacent to Martville it is unrecognized in the sections, its place being taken by a calcareous or a limestone-interlarded shale. Whether this is contemporary or successive is not now evident, but since it is a marked zone with black pebbles in its upper layer in five consecutive wells and again in the well at Lakeport (compare text-figure 4) it is here given separate consideration. The problem of these thin lentils in the lowermost Clinton will be considered in the chapter on "Physical History."

BEAR CREEK SHALE

At the old "Wolcott ore bed" on Bear Creek (9: 68, Black Creek of the topographic map) Hall found an interesting pelecypod fauna (2: 76-

[9] Professor Schuchert pertinently inquires whether these Martville and Bear Creek faunas may not be Medina rather than Clinton in content. To the writer they seem rather to help efface the old sharp line between the two "groups."

77) in the shale just *beneath* (3:83) the Furnaceville ore (9:22, 68), wrongly identified by him with the upper (Wolcott Furnace) ore. The fossils are:

Lingula oblata
Lingula subelliptica
Palæoglossa acutirostris
Pterinea leptonota (*emacerata?*)
Modiolopsis subalata
Ctenodonta machæriformis
Ctenodonta curta
Ctenodonta mactræformis
Ctenodonta? lata
Orthodesma curtum
Cuneamya alveata
Pyrenomœus cuneatus
Cyclora? subulata
Bucania bellapuncta
Dawsonoceras americanum[9]

The three feet of beds below the Furnaceville ore at Rochester formerly embraced in either the lower shale (8:13) or the lower limestone (12: 305) are referred to this horizon (compare Conrad's annual report for 1836, page 176) and are believed to be the source of all the fossils reported from the lower shale, both here and at Ontario, including the crinoid of 3:181, plate Axli, figure 6, of which a nearly entire specimen is at hand from Rochester. If distinct from the Martville, the Bear Creek shale will lie above rather than below it. (See the Lakeport well.)

OTSQUAGO SANDSTONE

This heavily cross-bedded red laminated sandstone is typically seen in and near the Otsquago Creek (spelled also Otsquak and Squak) below Vanhornsville (1:80-81), whence it extends westward with gradual loss of color to near New Hartford (1:85), where it seems to merge into the supposed Martville. From Vanuxem's belief (1:83) that it was cut off westward by the disconformity seen at the top of Blackstone's quarry, it may be a distinct member wedging in above the "Martville," or equivalent to the Bear Creek. The record of the Lakeport well favors the last (see figure 4), as does the occurrence of Pyrenomœus near Utica. No other fossils seem to be reported from it.

A typical illustration of the remarkable structure of this stratum is given in plate 2 of Hartnagel's paper on the Oneida (7, opposite 32).

FURNACEVILLE IRON ORE

Hartnagel, 1907 (8:14). The lowest Clinton ore bed anywhere recognized in New York extends from the Orleans-Monroe County line (letter from Ira Edwards) unbrokenly to Sterling Station, supposedly reappears as an oolitic ore in the Brewerton and Lakeport wells, but fails at Verona and eastward. As noted by Schuchert (12:305), it is decidedly a shal-

low-water deposit,[10] and its basal contact at Rochester suggests to the writer a disconformity, probably the same as that at Blackstone's. In any case the bed marks the introduction of a varied fauna, much of which yet remains to be studied. It includes:

Buthotrephis gracilis	*?Semicoscinium clintoni* (3:50)
Peronosporites globosus	*"Orthis" trinucleus* (3:74)
Peronosporites minutus	*Strophonella patenta?*
Peronosporites ramosus	*Hyattidina congesta*
Enterolasma caliculus ?	*Cœlospira nitens* (*"hemispherica"*)
Caninia bilateralis	*Cœlospira plicatula*
Ptiloporella ? sp.	*Botryocrinus plumosus*
Phænopora constellata (9: Pl. 3)	*Tentaculites minutus*
Phænopora ensiformis ?	*Actinoceras vertebratum*

The basal shale at Niagara likewise holds *Cœlospira nitens* and *plicatula* (10: 7; 12: 309) and Pterinea (?). We can not at present feel sure what this shale represents, but it is surely not the Maplewood ("Sodus" of Rochester).

DARK SHALE IN LAKEPORT WELL

It would be hazardous to draw any parallel between this and the bed at Niagara just mentioned. Since it is not known to outcrop in New York, it can not be named.

REYNALES LIMESTONE

If the shale equivalent of the Lower Clinton limestone of Rochester carries any Pentamerus at its sole exposure in the town of Wolcott, namely, at the old ore bed on Bear Creek, this fact could hardly have escaped such acute observers as Hall and Vanuxem. Hall distinctly mistook this stratum there for the upper—that is, Williamson—shale (2: 75).[11] The true Pentamerus limestone of Wolcott furnace, which must inherit the name Wolcott limestone, is a higher bed. The only complete exposures of the lower limestone, in its typical western develop-

[10] The problem of the origin of these ores has been treated by Smyth in Am. Jour. Sci. (1892), vol. 43, pp. 487-496 (Am. Geol., vol. 10, pp. 122-124). All the ores seem to be marine, or at least to contain marine material, perhaps reworked. They must, however, have accumulated exceedingly slowly, each through a long time interval, during which the supply of ordinary clastic sediment was nearly suspended. A certain amount of wave-ablation and of concentration of previous deposits may also have gone on, removing the finer particles and converting the coarser into ore—in the landward zone by oolitic coating of sand grains; in the more open waters by ferruginous replacement of calcareous fragments. These processes constituted pauses in the ordinary sedimentary record, perhaps of the type that Professor Barrell calls a "diastem," and they are from time to time contemporary with diastrophic readjustments.

[11] In his second annual report, 1838, p. 327, Hall reports the Wolcott ore bed as "immediately below the Rochester shale."

ment as such, are at Rochester, Lockport, and Niagara, where available formation names are exhausted. The largest fauna of this division is that reported by Hall (3) from Reynales Basin (also spelled Reynolds, 2 : 71), eight miles east of Lockport (10, map; 2 : 63), and while we must go to Lockport or the Rochester gorge for the typical section this name Reynales automatically connotes a very definite faunule, including:

Fungispongia irregularis
Favosites favosideus
Favosites hisingeri?
Caninia bilateralis (*marcoui?*)
Cannapora junciformis
Halysites catenularia?
Acanthoclema asperum
Helopora fragilis
Phænopora constellata
Ptilodictya (*obliqua?*)
Diamesopora tubulosa
Rhipidomella circulus
Rafinesquina corrugata
Strophonella patenta
Platystrophia brachynota (2 : 71)
Hyattidina congesta
Camarotœchia? bidens
Camarotœchia neglecta
Cœlospira plicatula
Pentamerus oblongus
Stricklandinia canadensis (Can.)
Botryocrinus plumosus
Ichthyocrinus? clintonensis
Holopea obsoleta
Hormotoma subulata
Bucania stigmosa
Oncoceras subrectum
Actinoceras vertebratum
Orthoceras virgulatum
Discosorus conoideus
Sphyradoceras? malti (unpublished)
Encrinurus ornatus
Goldius sp. nov.

Also probably *Clintonella vagabunda*, *Atrypina clintoni*, *Clorinda areyi*, *Ptilograptus hartnageli*.

Westward the Reynales limestone is persistent as a massive member to the last exposure (12 : 316), but eastward it grades into shale, finally indistinguishable in the sections from the Sodus shale above it.

STERLING STATION IRON ORE

Unfortunately this seems to be the only name available and unpreoccupied for the 4-inch seam of ore 8 feet above the principal ore bed (Furnaceville) at Sterling Station (9 : 57) which is not known to outcrop elsewhere, but appears in several wells. Fossils unknown to the writer.

SODUS SHALE

Hartnagel, 1907 (8 : 13), emended. Hartnagel defined this name as from the town of Sodus, "where this division is well shown in the vicinity of Sodus bay"; but, misled by Hall's error, he extended it to the basal or Maplewood shale at Rochester. Near the mouth of Salmon Creek, nearly two miles west of Sodus Bay, Hall reports the lower members of the Clinton group (2 : 66, 42), but the basal shale must there be very thin[12]

[12] "At Cental's mill, near Sodus Bay, . . . the green shale below [the Reynales] is but two or three feet thick" (Hall: Ann. Rept. for 1838, p. 328).

(only five feet in the Wallington well just south) and is probably all Bear Creek instead of Maplewood, or equivalent to only the upper 3 feet of what has been called "Sodus" at Rochester. It would be absurd to attach the name Sodus permanently to this feeble unit, which is below water level (9 : 21-22) at Hall's favorite collecting grounds around Sodus Bay, where his "lower green shale" is the middle shale, with its purple-brown middle part (2 : 59, 60) and thin intercalated "pearly" limestones (2 : 60) filled with fossils (2 : 66). This shale, which constitutes the major part (18 feet) of the *"upper"* shale at Rochester, and which, inclusive of the olive portions at base and summit, reaches a maximum of 69 feet in the South Granby well (nearly 55 feet at Sodus), is therefore the true Sodus shale. It is perhaps the most persistent member of the group in New York State, traceable almost to its eastern terminus. It carries:

Lichenalia concentrica	*Tentaculites minutus*
Dalmanella elegantula var. (3 : 57)	*Strepula?* sp.
Rafinesquina corrugata	*Beyrichia lata*
Atrypa reticularis (3 : 72)	*Bollia lata*
Cœlospira nitens (*Vanuxem*)	*Phacops trisulcatus*
Strophostylus cancellatus	*Calymenella rostrata*
Strophostylus ventricosus	*Calymene vogdesi?*

The "pearly layers" consist chiefly of the shells of the *"Orthis nitens"* of Vanuxem (1842, 1 : 90), whose description is perfectly recognizable (as first pointed out to me by Mr. Ira Edwards) and whose specimens are before me—usually identified with the European *Cœlospira hemispherica* (Sowerby, 1839). Equally abundant in the purple shale is the *"Stropheodonta" corrugata,* which is plainly a Rafinesquina, as it has no hinge denticulations.

VERONA IRON ORE

This ore, typically exposed in the old workings north and west of Verona (9 : 67, map on 66, 26, 40), is herein identified with the highly important oolitic lower ore of the Clinton region[13] and eastward. A similar shoreward transition is found to affect all the ores when traceable far enough to eastward, whereas westward they grade into limestone as does this ore in the Lakeport well. Its fauna is unknown, except that Vanuxem found *Beyrichia? lata* in it near Utica (1 : 84). *Dictyonema scalariforme, Cyclograptus rotadentatus,* and *Palæodictyota clintonensis* are from the shale that "directly overlies" it (New York State Museum, Memoir 11, page 185). The writer obtained Cyclograptus from the ore itself.

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[13] See preceding footnote 6, p. 338, which suggests caution.

WOLCOTT LIMESTONE

Hartnagel, 1907 (8:14-15), emended. Here, again, in following Hall, two horizons were confounded in the original description, namely, the lower and the middle limestones; but the type locality was specified as "Wolcott in Wayne County," and emphasis was laid on the "large brachiopod *Pentamerus oblongus.*" But in the type region specified this fossil fails in the lower (Reynales) limestone at its sole exposure, on Bear Creek, six miles northeast of Wolcott, which is there so shaly that Hall (2:66, 64) mistook it for the upper shale. The name Wolcott limestone, therefore, must clearly be restricted to the rock which *is* a limestone and *does* carry Pentamerus and which alone of the two limestones crops out on Wolcott Creek, namely, at the old Wolcott furnace, just north of Wolcott village (9, figure 3; 2:66). Its thickness in the Wolcott test well is nearly 22 feet. Wolcott village itself is on fossiliferous Rochester shale, which may have caused the citation (13:95, 858) of two Rochester shale species as from the Wolcott limestone.

Though absent at Rochester and westward, where the Reynales has masqueraded for it, the Wolcott limestone (shale to east and north) is an important member in all sections from Wayne County to Clinton and its fauna should be fully investigated. The only species now known with certainty are: *Semicoscinium clintoni* (Vanuxem, 1:87, 89), (*"Fenestella prisca?"* Hall), *"Fenestella" tenuis* (3:51; compare 2:62, 66 for location), *Pentamerus oblongus* (9:21, 31, 32), *Calymene clintoni* (3:298). Vanuxem (1:89) reports "a specimen" of *Spirifer niagarensis,* but this needs confirmation.

Vanuxem's specimens of his *"Clinton retepora"* (on which he based his correlations now confirmed by the State drillings) are before me from Verona and Martville, bearing the Survey label (Hall's?): *"Fenestella prisca."* This form is highly characteristic of these beds and will probably prove distinct from *S. tenuiceps* of the Rochester shale. Our Verona specimen contains also a pygidium of Calymene, probably vogdesi.

In the shales above the oolitic ore at Clinton, which seem to occupy the Wolcott horizon, the following graptolites occur (New York State Museum, Memoir 11):

Cactograptus crassus
Dendrograptus rectus
Dictyonema retiforme
(collected by the writer)

Also, close to the ore,
Palæodictyota clintonensis
Palæodictyota bella recta
Cyclograptus rotadentatus
Dictyonema scalariforme

The finding of the Rochester Dictyonema in these dark blue-green

shales far down in the Clinton, like the recent discovery of the "Clinton" (Brassfield) *Dictyonema pertenue* in the Rochester shale at Rochester, proves only that these species have a less restricted vertical range than is commonly assigned to the graptolites.

WOLCOTT FURNACE IRON ORE

This is another unsatisfactory name, with all else preoccupied, unless we use some other binomial, such as "Shaker settlement" or "Second Creek," from the other, rather dubious, occurrence near Alton. The bed crops out at the old Wolcott furnace on Wolcott Creek, a mile north of Wolcott village, but is of limited extent even in the wells. It appears to carry the two bryozoans of the limestone below, and perhaps also *Spirifer radiatus* (3 : 66) and Halysites (3 : 44).

WILLIAMSON SHALE

Hartnagel, 1907 (8 : 15-16), restricted. Hartnagel does not specify his type locality, but as he was following Hall he doubtless had in mind Hall's only mention of Williamson (2 : 66), which reads: "In the eastern part of Williamson, a little north of the Ridge road, the green shale with graptolites occurs, and a short distance to the north of this the Pentamerus limestone." This may mean the outcrops on Mink Creek at the cusp of the "ridge" (Iroquois beach) between Williamson and East Williamson villages. In any case the mention of the graptolites (compare 2 : 75, where the species are described) fixes the horizon, while it is evident from the chart that the limestone a "short distance" north must be the true Wolcott rather than the Reynales. Since the so-called Williamson or upper shale at Rochester includes both the graptolite shale and (in the absence of the Wolcott limestone) the Sodus purple shale beneath, we must either restrict the name to the graptolitic beds as here done or else, if the usage at Rochester be insisted on, abandon it altogether. The Williamson as restricted by Hall's locality reaches the extreme of 105 feet in thickness in the Lakeport well as against its five feet at Rochester and possible failure at Clinton. These rapid changes in bulk indicate some minor diastrophic movements just prior to its deposition, as is brought out by text-figure 3. Its fossils are:

Monograptus clintonensis
Retiolites venosus
Semicoscinium tenuiceps (?)
?*Palæoglossa perovata*
Pholidops squamiformis
Plectambonites elegantulus (2 :73)
Chonetes cornutus
Spirifer radiatus
Camarotœchia emacerata
?*Atrypa reticularis*
Leptodesma rhomboidea
Modiolopsis subalata

Leptæna rhomboidalis
?Rafinesquina corrugata (3:71)
Schuchertella subplana var.? [14]
Orthoceras sp. nov.
?Calymene clintoni
Bollia? lata

BREWERTON SHALE

From the shales at Brewerton, which Hopkins (11: 7) calls "bluish" and Burnett Smith (11: 57) "olive," dredged out of the Barge canal, Smith obtained (11: 58):

Rusophycus biloba
Pholidops squamiformis
Atrypa reticularis
Pterinea emacerata
"*Orthonota curta*"
Conularia sp.
Orthoceras sp.
Klœdenella symmetrica (?)
Arctinurus boltoni [var. nov.]
Calymene sp. [*clintoni*]

Although we have already presented evidence that this fauna must lie a long way below the true Rochester shale (see figure 2) and scarcely above the Williamson shale, yet it is mostly a list of Rochester shale species in which Rusophycus and *Orthonota curta* are the only distinctly Clinton components. It is entirely probable that more of the Rochester species range downward into the Lower Clinton members than the lists already given would betoken, but even so this fauna forges a further link with that later congeries. Just how much of the shales overlying, or of those in the adjacent wells, is to be referred to this faunal zone is uncertain; but we have rather confidently assigned here the 26 feet of fossiliferous shales just under the Kirkland limestone in the Lakeport column, which terminate downward with a black pebble seam. Much further work is needed to determine the limits and areal extent of this division, which is of great moment in the stratigraphic and faunal succession.

KIRKLAND IRON ORE

This is really a ferriferous limestone, conspicuously crinoidal, and is known locally as the "red-flux bed." Its finest exposures are across the town of Kirkland, in which lies Clinton village, though it is traceable to Steeles Creek (1: 82), where it has furnished Crinoid joints (1: 79, figure 3), *Beyrichia? lata, Calymene clintoni.* On Swift Creek (1: 84-85) it or the associated rocks carry *Leptæna rhomboidalis, Rafinesquina clintoni* (1: 84; *R. obscura* of Hall, 3: 62).

[14] This species would appear to the writer to be a Schellwienella, as that genus is defined by Weller in his "Mississippian Brachiopods." It is not the species identified as *S. subplana* at Waldron, Indiana (*S. hemiaster* Winchell and Marcy).

VANHORNSVILLE SANDSTONE

Though the exposures of this red, coarse hematite-quartz mixture at Vanhornsville (1: 80, 81; 3: 15) are meager, the rock itself is indubitable and striking. Its possible equivalency has been already mooted.

From the "shaly laminated sandstone highly charged with oxide of iron, associated with the iron-ore beds in the town of Kirkland" (3: 64), Hall gives:

Leptæna rhomboidalis (1:86)
Rafinesquina clintoni (*obscura*)
Strophomena? orthididea
Stropheodonta prisca
Whitfieldella? sp. (3:78, Pl. 24, f. 5)
Pterinea emacerata
Diaphorostoma sp.

This fauna can scarcely lie lower than the Brewerton, while the rock suggests a westward extension of the Vanhornsville.

From about the same horizon came probably the types of *"Palæophycus"* (*Eophyton?*) *striatum,* and perhaps also *"Orthis" tenuidens.*

PHŒNIX OR SCHRŒPPEL SHALE

The type locality is at Phœnix, on the Oswego River, where Burnett Smith (11: 57, 58) obtained the following faunule:

Chasmatopora angulata
Leptæna rhomboidalis
Plectambonites transversalis
Atrypa reticularis affinis
Spirifer (*Eospirifer*) *radiatus*
Pterinea emacerata
Kionoceras subcancellatum
Dawsonoceras americanum
Orthoceras sp.
Calymene sp.
Dalmanites limulurus

From the proximity of the Lockport limestone at Three River Point (11: 9), and of the lower Rochester shale nearly due east of Phœnix, this is high up in the Clinton group, to which its olive color assigns it. The rifts in the river (1: 89) indicate a firmer rock-mass than that at Brewerton, such as the upper 62 feet of Clinton shale in the Lakeport well with its intercalated sandstones, which again is connected by numerous outcrops (1: 89, 272, 87) with the upper sandy layers at Clinton and Utica. These last localities supply the following additional forms:

Rusophycus biloba
Palæophycus bacterium, nom. nov.
Conostichus? circulus, nom. nov.
Aristophycus?? sp. (3:Pl. 10, f. 5)
Palæocyclus rotuloides
Lingula tæniola (3:55)
Rafinesquina clintoni (*obscura*)
"Stenoscisma" sp. (1:89)
?Pentamerus ovalis
?Diaphorostoma sp.

Westward the sandy layers at this horizon drop out and then thin limy ones come in, increasing until finally the division seems to merge into the

Irondequoit limestone. Whether the lower shaly part of this limestone at Rochester contains any representative of the Brewerton is not yet determined; it is not very productive, except for *Buthotrephis crassa,* and has not been carefully collected from, but *Rusophycus biloba* and *Eophyton? striatum* occur in a brilliant green shale film at the basal contact zone.

Since "Phœnix" has been used by Keith for a limestone lentil in Utah and by Daly for a volcanic formation in British Columbia, recourse may be had, if necessary, to Schrœppel, the township in which Phœnix lies.

HERKIMER SANDSTONE

This name is derived from Herkimer County and is here applied to the Upper Clinton "gray band" of Eaton, which stretches conspicuously across the southern part of this county with a maximum thickness of 70 or 80 feet at the type locality on Steeles Creek (1:81-82, 257; name preoccupied), five miles southwest of Herkimer village, where it has yielded (3:100-105):

Mytilarca mytiliformis
Modiolopsis ovata
Modiolopsis subcarinata
Ctenodonta elliptica
Orthoceras clavatum
Trimerus delphinocephalus
"*Ichthyodorulite*"

As a part of this congeries, but from localities farther west that seem to belong to the Phœnix division, Hall has described also:

Rafinesquina obscura? (probably *Schuchertella subplana!*)
Pentamerus ovalis
Diaphorostoma sp.

These have been listed under the Phœnix, of which we believe the Herkimer is indeed only a sandstone phase, as before argued, and as Hall apparently suspected.

DONNELLY IRON ORE

The ore "at Thomas Donnelly's" (1:88) has been correlated (9:26) with the thin seam at the base of the upper Irondequoit (Lakeport) limestone in the Lakeport well and with that at Tipple's quarry, near Verona (1:87), all of which are above the Phœnix and close to Lockport quarries. Vanuxem (1:89, 272) describes other doubtful exposures along Oneida Lake and a 2-foot bed of ore at Joscelin Corners, only a mile or so from the drilling. He lists from Donnelly's the following, two of which occur also at Tipple's:

Leptæna rhomboidalis
Spirifer (Eospirifer) radiatus
Atrypa reticularis affinis
Pentamerus "oblongus" (ovalis?)

IRONDEQUOIT LIMESTONE

Hartnagel, 1907 (8: 16-17). In its lower shaly half at Rochester the Irondequoit limestone appears to comprehend western phases of the Phœnix, or perhaps Brewerton (text-figure 3 illustrates the causes of uncertainty), and it is even possible that it embraces an important hiatus, in which case the name might be restricted to the upper crystalline part with its curious "reefs" [15] and Rochester fauna. Preferably it could be retained in its original scope for the western sections not susceptible of easy subdivision. It is interesting to note that Hall hesitated whether or not to include the Irondequoit limestone in the Rochester (Niagara) shale, and felt obliged (2: 82) to present his reasons for adding it to the Clinton. These reasons still apply to its lower and major portion. The fossils listed are derived mostly from the upper half:

Buthotrephis gracilis crassa
Receptaculites tessellatus
Favosites niagarensis?
Chilotrypa ostiolata
Hallopora elegantula
Orthis flabellites
Bilobites biloba
Rhipidomella hybrida
Brachyprion profundum
Leptæna rhomboidalis
Spirifer radiatus
Spirifer crispus (8:17)
Cyrtia meta
Rhynchotreta americana (12:310)
Rhynchotreta robusta (10:7)
Camarotœchia acinus (5:193–194)
Camarotœchia neglecta (8:17)
Atrypa reticularis affinis
Atrypa nodostriata
Whitfieldella nitida
Whitfieldella cylindrica
Whitfieldella intermedia
Whitfieldella naviformis
Anastrophia interplicata
Clorinda fornicata
Pisocrinus globosus
Pisocrinus pyriformis
Stephanocrinus gemmiformis
Closterocrinus elongatus
Caryocrinites ornatus
Strophostylus cancellatus? (3:91)
"?" *Cyclostomiceras? abruptum*
Protokionoceras crebescens (?)
Dawsonoceras americanum
Cycloceras "imbricatum"
Cornulites clintoni
Calymene niagarensis
Trimerus delphinocephalus
Bumastus ioxus
Perhaps also:
? *Goldius niagarensis* (13:559, 1488)

Except for the forms that are unique, this list is overwhelmingly of Rochester species, though it still lacks over one hundred of the indicial species of the Rochester shale.[15] It is hard to see on what grounds it should be subordinated to the Clinton group. We have in the uppermost beds usually assigned to the Irondequoit limestone a great inrush of the Rochester-Waldron fauna. These beds have more than twice as many species

[15] Sarle (Am. Geol., vol. 28, p. 284) reports 99 species as found in the "reefs," but his lists of species are not published. See also Am. Nat., vol. 16, p. 711; Am. Geol., vol. 1, p. 264; Rept. N. Y. Pal. for 1899, p. 672, and for 1901, p. 428.

in common with the Waldron shale as with the Osgood beds, and especially such index species as *Clorinda fornicata, Camarotœchia acinus, Brachyprion profundum,* and *Whitfieldella nitida.* Consequently we may, perhaps, have to approximate the Waldron and Laurel more closely to the Irondequoit and the Osgood to the Brewerton when we know these New York faunas better.

LAKEPORT LIMESTONE

Immediately below the typical fossiliferous Rochester shale and above the Donnelly ore in the Lakeport hole there are 16 feet of "limestone with considerable shale" (9 : 38) that have been interpreted by Hartnagel (9 : 25) as summit Clinton. Corresponding to these in position in the South Granby well, the next hole west to penetrate this horizon, are but 18 inches of "impure limestone with fossils" "grading apparently into the" Rochester (9 : 36, 24). Without knowledge of their fauna the importance of these beds can not well be evaluated, so it will be safer to employ temporarily a local designation for them. The underlying Donnelly ore crops out at Joscelin's Corners (1 : 89; 9 : 26) and elsewhere in the vicinity of Lakeport, and must expose some portion of this limestone along with it.

Conditionally we may follow Hartnagel's apprehension of the mass as summit Clinton, but whether uppermost Irondequoit coordinate with the "reef" zone at Rochester or a new intercalated member is as uncertain as the third possibility—that it is a calcareous eastern facies of the lower true Rochester (above the "reef" horizon). The last suggestion gathers force from the fact that, contrary to the Clinton rule, the Rochester shale grows more calcareous in passing eastward from Niagara to Rochester—a tendency that may still prevail toward the east, where its outcrop is under the drift.

Upper Limit of the Clinton

The higher beds at Clinton contain small faunas consisting largely of Rochester shale species, from which it has been argued that the Rochester horizon is itself present in the type Clinton section. But the drillings show that these beds lie below the Rochester around Oneida Lake, with the Lakeport (upper Irondequoit) limestone and Donnelly ore intervening. The Rochester shale, which is at least 75 feet thick at Wolcott[16] (Hall thought it nearly 100; 2 : 97), has thinned to 29 feet at Lakeport, though still quite recognizable, and is wholly unknown east of this well. The only apparent bond between this dwindling shale and the 70-foot

[16] Including probably the division presently to be distinguished as the Gates.

mass of Herkimer sandstone east of Utica is the trilobite Trimerus, but Hall says of this that it ranges "as low as the ferruginous sandstones of Oneida County, which appear to be near the base of the formation" (3:299).

To complete the adverse evidence on this point, the nature of the unconformity at the summit of the Clinton should be studied on the chart (figure 2) and in text-figure 3. The Lockport dolomite, still probably 150 feet thick in the Syracuse wells, has become possibly 75 feet (mostly shaly) at Clinton and scarcely separable from the overlying Pittsford horizon (see New York State Museum Memoir, 14:421), which is probably the rock that makes its last appearance on Steeles Creek (1:90). At Tisdales all these are gone, and a still higher Silurian formation, the Vernon shale, rests directly on the Herkimer sandstone, with a thickness of possibly 50 feet (1:96, 258), though it was fully 80 feet at Steeles (1:96) and 150 at Clinton (W. J. Miller, New York State Museum, Bulletin 107:150). At Crills, five miles beyond Tisdales, the Vernon is wholly lapped out, and the overlying Camillus gypseous shales of the higher Silurian repose directly on the lower part of the Herkimer sandstone (1:100, 258), which does not show itself again beyond this place. At Vanhornsville the upper members of the Camillus come down within a few feet of the red hematitic sandstone (1:81, 99), and in a short distance beyond they are in contact with the Ordovician Frankfort shale (9:28; 1:253; New York State Museum Bulletin, 162:36), the Clinton having disappeared; compare text-figure 3.

There is thus a steady loss of members from both the top of the Clinton and the bottom of the Niagara and Salina as the hiatus enlarges eastward. To whichever group we refer the Rochester, it should therefore be one of the first to go; indeed its sharp reduction in the Lakeport well was our first intimation that this process of elimination had commenced as we came east. Along with it vanishes the upper Irondequoit (Lakeport) and then the Donnelly. The resistant Herkimer, however, persists eastward as an ancient cuesta, with a steep in-face.

Stratigraphically, then, the Rochester shale is excluded from the type section of the Clinton. Considering the Waldron aspect of the upper Irondequoit fauna as just observed, the paleontologic testimony is not any more favorable. The comparatively small number of "Rochester" species in the upper Clinton divisions (Brewerton, Phœnix, Donnelly, Kirkland, Herkimer) loses all weight when it is realized that Plectambonites, *Spirifer radiatus,* Leptæna, Pterinea, Dalmanella, Atrypa, Semicoscinium, Dawsonoceras, Trimerus, Calymene, Dalmanites, *Camarotœchia neglecta, Dictyonema retiforme* and *areyi,* all get started either in or below the

Williamson shale, whereas in none of the Clinton divisions does there appear more than a mere fragment of the large and typical Rochester fauna (about 230 species recorded; see 8 : 19 ; 10 : 7; 13 : 1487-1489) except in the upper Irondequoit, especially its "reefs."

On the other hand, the sifting of the faunules reveals a surprising incoherence faunally in the stratic units of the Clinton itself. There is here no discernible "Clinton fauna" in the sense in which there is a Hamilton fauna or a Naples fauna. While intensive collecting may give greater homogeneity to the stratic paleontology, the larger disconformities will always isolate rather definite assemblages, as will be further shown after the physical evidence for these disconformities has been presented.

Physical History

The straight-line correlations of figures 1 and 2 fail to bring out vividly the diastrophic movements, with their resultant overlaps, often alluded to above. To visualize these, and to bring together all the sections on a uniform scale, text figures 3 and 4 have been prepared. While drawn to measurement with the same care as the plates, the sections have been connected in these diagrams by smooth curves, so as to reconstruct more nearly the actual strata. As a result, some things that before appeared as difficulties now prove highly significant. For instance, the apparent excess at the summit of the Red Creek section (see figure 1) serves to locate an accessory syncline in figure 3 (section "6"). Similarly the deficient thickness of the Reynales limestone at Ontario marks a secondary anticline in figure 4 (section "2").

The strata in figure 3 are given the attitude they are believed to have had approximately during Rochester time. The overlying formations are then fitted over these in their proper thicknesses, in order to emphasize the great summit unconformity and the cuestas of firmer rocks over which the Mesontaric sea transgressed eastward.

At the east a similar basal unconformity of the Oneida conglomerate on the Ordovician shales has long been recognized, and it has been correctly argued (by Grabau and others) that the amount of summit erosion of these shales demands a later age for the Oneida than pre-Medina or (as some have even thought) Oswego. In short, here also was an eastward transgression.

Next most striking is the evidence of a post-Wolcott diastrophism—a weak compression from the east, producing a marked syncline in the region of Oneida Lake, with its maximum at Lakeport (section "9"). Simultaneously the bordering regions rose into the zone of wave-plana-

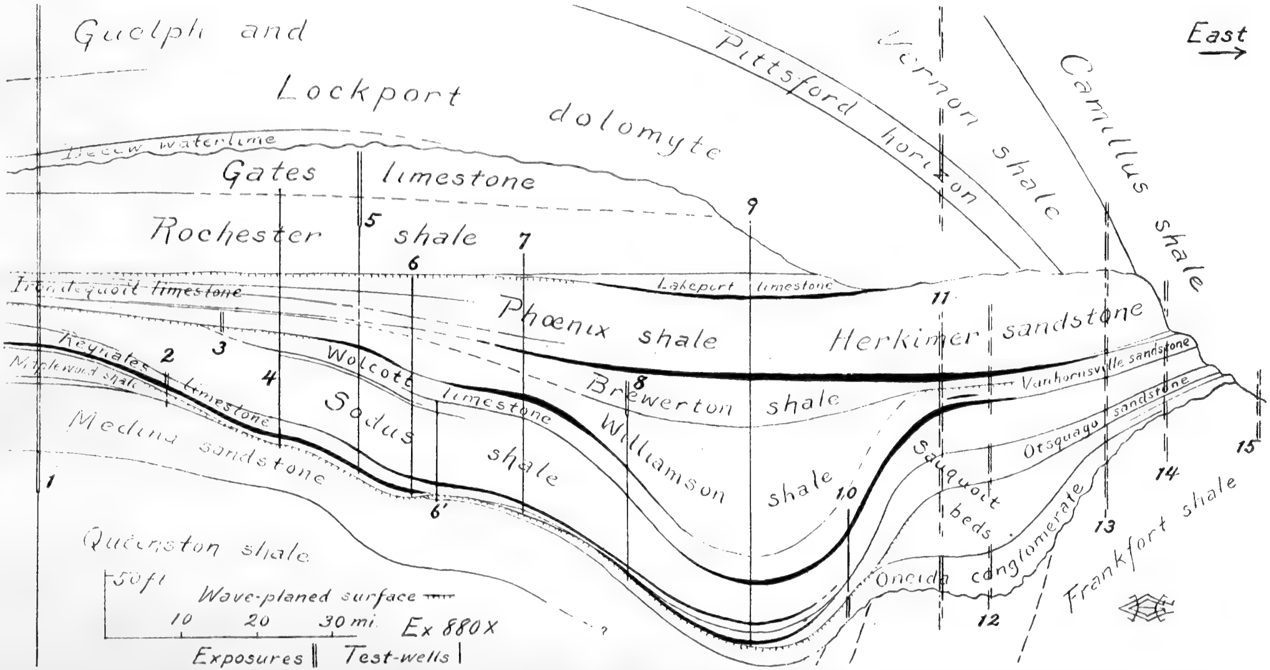

FIGURE 3.—*Reconstructed stratigraphic Diagram of Eontaric Strata and overlying Beds from Rochester to pre-Niagaran erosional Limit of the Series in present Line of Outcrop*

For correlation, compare figures 1 and 2. Single vertical lines are the bore-holes and double lines are exposures, numbered as follows: 1. Rochester. 2. Ontario. 3. Williamson. 4. Wallington. 5. Wolcott. 6. Red Creek. 6′. Martville. 7. South Granby. 8. Brewerton. 9. Lakeport. 10. Verona. 11. Clinton. 12. Utica. 13. Tisdales. 14. Vanhornsville. 15. Cherry Valley. Thickness of the iron-ore bands (in black) slightly exaggerated.

tion, as should be expected. Hence, while the sub-Williamson formations maintain a marked uniformity of thickness in sections "4" to "10," they are rapidly beveled away from the top downward to the west of section "4" (Wallington) and are overlapped successively by the much attenuated Williamson. At Rochester, where the Williamson is very thin and rests directly on the lower Sodus, it contains slightly rounded flat pebbles of limestone at and near its basal conduct, often standing obliquely and sometimes two or three inches in diameter. There are also in the shale worn favosite corals of similar size whose calcareous or yellowish matrix indicates extraneous origin, presumably from wave destruction of neighboring Wolcott limestone.

The strata above the Williamson do not participate in the undulations of the sub-Williamson beds, except that the Brewerton sags slightly into the main (Lakeport) trough. But a general excess of upward movement at the west seems to have persisted until the close of Irondequoit time, maintaining clear-water (but shallow) reef[17] conditions from Niagara nearly to Rochester and catching all the land wash in the sinking hinterland to the east.

The nature and distribution of the Rochester shale show that these canting movements suddenly ceased and a general submergence ensued, whose terrigenous sediments appear to have come largely from a new direction (farther west). Further field-work is necessary before the nature of the sub-Rochester plane can be confidently asserted, as also the relations to the upper Irondequoit and Rochester of the Lakeport limestone. One gathers from figure 3 that the Lakeport would go more accommodatingly below rather than above the wave-erosion plane. Provisionally, however, the line has been drawn at the Donnelly ore.

Another marked feature of the diagram is the great expansion already described (page 337) of the basal beds at Clinton (section "11"). This is now seen to be due to an earlier (pre-Martville) diastrophism, in which was produced the Sauquoit synclinal. The beds involved are the Oneida and supposed Maplewood. The effects of this movement farther westward are best brought out by means of the extreme exaggeration given to the thin basal members in figure 4, in which the summit of the Reynales limestone is taken as the horizontal datum. Two movements are evident in this figure: First, the post-Maplewood Alton anticline (corresponding to the western rim of the Sauquoit syncline just mentioned), and, second (after wave planation and deposition of the Martville-

[17] This has no reference to the so-called local "reefs" of the increscent Rochester submergence, but to the crinoidal and other organic rubble of which the Irondequoit itself is composed.

Otsquago-Bear Creek), another faint compression that converted the erosion-weakened crest of the previous arch into a double anticline before the Reynales limestone was deposited. Less evident from the diagram is an overlap relation of the Thorold-Maplewood on the red Medina, which would be more easily demonstrated had the wells penetrated deeper.

These diagrams indicate the following "order of events":

(1) Post-Ordovician erosional unconformity and transgression.

(2) Post-Maplewood diastrophism—Sauquoit syncline, Alton anticline.

(3) Post-Wolcott diastrophism—Lakeport syncline, Rochester parma.

(4) Pre-Rochester submergence; source of sediment shifted to west.

(5) Pre-Lockport erosional unconformity, terminating the Eontaric.

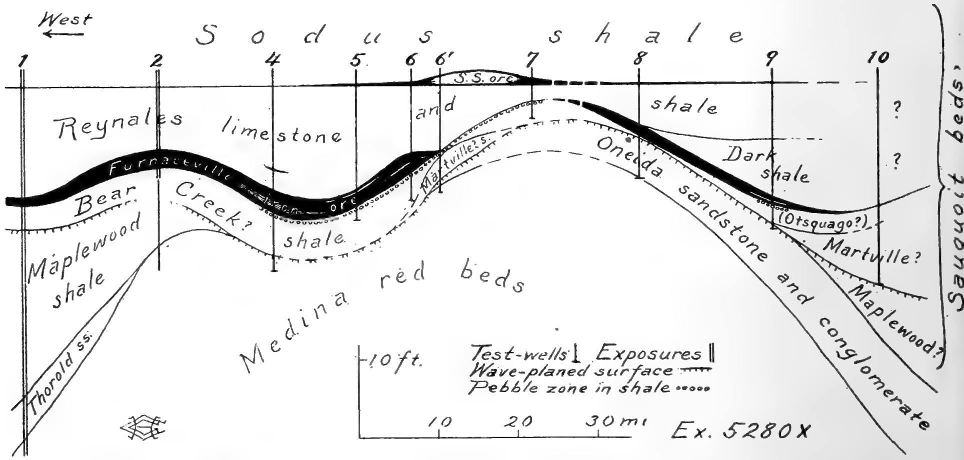

FIGURE 4.—*Diagram of thin basal Divisions of the "Clinton," from Rochester eastward to Verona only*

The vertical exaggeration is excessive. Solid vertical lines are the test-wells terminating in these strata and are numbered as in figure 3. Oneida conglomerate largely inferred from outcrops to north; it may extend farther west. The diagram suggests that Bear Creek sedimentation was both preceded and followed by faint diastrophic movements, and that these movements were initiated still earlier at the close of Medina red-bed deposition. Iron ore in solid black. The horizontal datum is the top of the Reynales limestone.

Interspersed between these are minor diastrophisms and those weaker pauses in deposition, such as Professor Barrell is calling "diastems," of which the various iron-ore beds furnish special illustrations. The most significant of these minor breaks seem to be those at (*a*) the top of the red Medina, (*b*) the Furnaceville iron ore, (*c*) the Kirkland iron ore, and (*d*) the base of the Gates limestone.[18]

[18] This name is defined at the beginning of the following chapter on classification.

The extent and importance of these interruptions in sedimentation are best exhibited by the following distribution chart of horizons. The localities are chosen to avoid duplication, and from Rochester east they are spaced at moderately equal intervals. Thin ore beds not associated with significant diastrophic changes are omitted. The asterisks signify presence of the horizon.

West	Limehouse, Ont.	Hamilton, Ont.	Niagara River	Lockport	Rochester	Ontario, N. Y.	Wallington	Red Creek	South Granby	Brewerton	Lakeport	Clinton	Tisdale's	Vanhornsville	East	
Mesontaric	Lockport dolomyte series (Decew, etc.)															
Gates		?			*	*	*	*?	?	?						
Rochester		*	*	*	*	*	*	*	*	*	*					
			?	?	?	?	?	?	*?	*?	*	?			Lakeport	
										*	*				Donnelly	
Irondequoit		*	*	*	*	*	*	*	*	*	*	*	*		Phoenix-Herk.	
			?	?	?	?	?	?	*?	*	*	*	*	*?	Kirkland	
Brewerton				?	?	?	?	?	?	*	*	*?	?			Unseparated at Clinton
Williamson					*	*	*	*	*	*	*	?				
Wolcott Furnace								*	*	*						
Wolcott						?	*	*	*	*	*	*?	?			
Sodus					*	*	*	*	*	*	*	*	*	*?		Sauquoit
Reynales ("Wolcott")	?	*	*	*	*	*	*	*	?	*?	*?	?	?			
Furnaceville			?		*	*	*	*		*?	*?					
Bear Cr.-Martville					*	*	*	*	*	?	*	*	*	*	Otsquago	
Maplewood ("Sodus")			*		*	*						*?	*?			
Thorold		?	*		*?			?	?	*	*	*	*	*	Oneida	
Medina	Cat.	*	*	*	*	*	*	*	*	?	?					
Ordovician	Queenston red sandy shales									?	?					

The hour-glass pattern of this chart is even more convincing than the diagrams, as to the prime import of the middle (post-Wolcott) disconformity. This break forms the natural division between lower and upper Eontaric.

Classification and Faunas

On the basis of these unconformities, disconformities, and "diastems" found in the New York strata, we may forecast some future readjustments in the classification of the Eosilurie (Eontaric). The summit of the

latter will be the great unconformity whose eastern manifestation has just been discussed and whose western development has been traced by Schuchert (12). No comparable break is known to exist further up between the Niagara and Salina. Its character is strikingly exhibited in the new barge canal rock-cut at Rochester, where, furthermore, there are beneath it about 20 feet of beds at the top of the Rochester shale which are apparently not present at Niagara and which are really a limestone, being quarried and sold as such at the North Goodman Street quarry in Rochester (12 : 304). These beds were noted by Hall (2 : 82). On their eroded upper surface rests the Decew (basal) member of the Lockport. They are separated from the shale below by a perfectly clean-cut line, or clay seam, and carry few fossils save *Lingula lamellata.* It is proposed to call this division the Gates limestone, from the town in which the beds appear in the canal prism, and to restrict the term Rochester shale to its proper expression as a fossiliferous calcareous shale below them.

The full list of horizons[19] from the Gates down to the Champlainic (Ordovicic), with its major (———) and minor (......) disconformities and the maximum known thicknesses in New York State, is:

Upper Eontaric

	Feet
22. Gates limestone [a]	20
....	
21. Rochester shale	65
20. Lakeport limestone.........	16
19. Donnelly ore [c]	2
———————————	
18. Phœnix shale and sandstone [b]	70?
17. Kirkland ore and limestone.	6
....	
16. Brewerton shale	36
15. Williamson shale	105
———————————	
	———
Total................	320

Lower Eontaric

	Feet
14. Wolcott Furnace ore [c].....	4
13. Wolcott limestone	23
12. Verona ore	5
11. Sodus shale	69
10. Sterling Station ore.......	1½
9. Reynales limestone	24
(Dark shale in Lakeport well	7)
8. Furnaceville ore [c]	2½
....	
7. Bear Creek shale and	
6. Martville sandstone [d]	10
———————————	
5. Maplewood shale [e]	21
4. Thorold sandstone [f]	10
....	
3. Grimsby (*Medina*) sandstone [g]	60
2. "Cataract" (*Manitoulin*) shale [g] (in New York)..	29
1. Whirlpool sandstone [h]	22
———————————	
———————————	
	———
Total................	281

About 475 species of fossils are known from these strata in New York and southern Ontario. With our present imperfect knowledge of the range of these species (particularly in the Wolcott limestone), it is not desirable to cumber these pages with an extensive tabulation by horizons; but an abbreviated summary by groups of strata will serve to show how few species are known to pass the diastrophic barriers above indicated. (The table appears on the following page.) The surprising thing about this table, however, is that the largest number of species in common between any two groups within the Eontaric is that between opposite ends, the Rochester shale and the Cataract-Edgewood-Brassfield faunas—23 species. This may have some paleogeographic meaning, or it may merely measure our ignorance of what lies in between. The Rochester has its largest quotas in common with the Niagaran faunas above it, whereas the Cataract-Medina fauna shows less species in common with the entire Ordovician (including Richmond) than with the Rochester, and especially with the unquestioned Niagaran (Lockport-Guelph, Louisville, etcetera). The small Martville-Bear Creek fauna is more largely unique (73 per cent) than any other (except the debated "Niagaran dolomite" of Hamilton, Ontario), and the large Rochester fauna stands next (67 per cent unique).

In confirmation of the deductions already made from the stratigraphy, it should be noted that the typical "lower Clinton" group (Furnaceville to Wolcott Furnace), which carries the largest assemblage between the Cataract and Rochester, has its faunal affinities most decidedly with the Cataract-Brassfield (23 per cent), whereas the overlying Williamson-Brewerton-Phœnix division aligns itself equally decidedly with the Rochester shale in its faunal association (25 per cent). The current reference of the Williamson Monograptus fauna to the lower Clinton has clearly

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[19] *a* The Gates probably continues to thicken east of Rochester under the drift, and is very likely the rock forming the falls at Wolcott village which Hall (2 : 82) speaks of as the "higher beds" of his Niagara shale. *b* The Herkimer, supposed equivalent of the Phœnix, is said to reach a maximum of 80 feet. *c* The iron ores (Donnelly, Wolcott Furnace, Furnaceville) really are *in* the disconformity rather than above or below it, since they represent concentrations of iron oxide during the depositional interruption; but their fossils are in general those of the adjoining limestone member. *d* The supposed equivalents of the Bear Creek and Martville forming the middle member of the Sauquoit beds about Clinton and Utica have there a thickness of approximately 30 feet (2 : 16). *e* The beds correlated with the Maplewood likewise approach 50 feet thickness in the Sauquoit syncline. *f* Should the "gray band" of Rochester prove distinct from the true Thorold, the list will need to be amended at this point. *g* The Grimsby and Cataract are equivalent beds of different facies, with contemporary overlap toward the west, as interpreted by Schuchert (12 : 294) ; in Canada the Cataract eventually embraces the entire interval, with a thickness equal to the sum of the measures here given, and is there subdivided into the Manitoulin dolomite below and the Cabot Head shale above. *h* The Whirlpool is considered by Professor Schuchert the basal member of the Cataract.

Preliminary Table of Distribution of the Eontaric Faunas of New York and Southern Ontario [20]

Horizons, grouped as in the list preceding.	Number of Species.					In common with other groups, namely:									
	From below.	+ Peculiar.	+ Pass above.	− Above & below.	= Total.	Ordovician.	Cataract, Medina and equivalents.*a*	Furnaceville to Wolcott Furnace.	Williamson to Donnelly.	Irondequoit.	Rochester shale.	"Niagaran dolomite," Hamilton.	Waldron.	Other higher beds anywhere.	Last three colums combined.
Cataract and Medina.	11	63	39	7	106	11	106	13	6	7	14	8	9	21	21
	10%	59%	37%	6%	100%	10%	...	12%	5%	6%	13%	7%	8%	20%	20%
Martville and Bear Creek.*b*	3	14	2	0	19 *c*	?	3	?	1	1	1	?	2	0	2
	16%	73%	11%	..	100%	..	16%	..	5%	5%	5%	..	11%	..	11%
Furnaceville to Wolcott Furnace.	21	43	18	9	73	4	17	73	4	1	8	7	2	8	12
	29%	58%	25%	12%	100%	6%	23%	..	6%	1%	11%	10%	3%	11%	17%
Williamson to Donnelly.	17	27	17	8	53	5	8	4	53	5	13	10	9	7	15
	32%	51%	32%	15%	100%	9%	15%	8%	..	9%	25%	19%	17%	13%	29%
Irondequoit, chiefly upper.	12	10	29	10	41	1	7	1	5	41	22	8	18	22	26
	29%	24%	71%	24%	100%	2%	17%	2%	12%	..	54%	20%	44%	54%	63%
Rochester shale with Gates.*d*	49	157	58	31	233	4	23	8	13	22	233	34	(39)	37	58
	21%	67%	25%	13%	100%	2%	10%	3%	6%	9%	...	15%	17%	16%	25%
Rochester and "Niagaran dolomite."	53	222 *e*	50	29	296	4	23	10	13	24	296		41	38	50
	18%	75%	17%	10%	100%	1%	8%	3%	4%	8%	...		14%	13%	17%

[20] The nearly barren Thorold and Maplewood are omitted. *a* Including Edgewood and Brassfield of Ohio, Illinois, and Missouri. *b* This small fauna is omitted from the vertical column to save space. *c* Besides about 20 "fucoids" from the Sauquoit area, mostly unique. *d* In this set of figures the "Niagaran dolomite" of Hamilton, Ontario (13 : 1489) is considered Lockport as by Parks and Schuchert; but the 157 species given as peculiar to the Rochester include those (namely, 9 species) that are common to the Waldron only, since the Waldron may prove equivalent. *e* *Excluding* all Waldron species—that is, following Bassler's correlation. This last set of figures is strictly supplemental.

resulted from the inclusion in the Williamson of the true Sodus shale, which is now found to be markedly disconformable with it, and with which it has almost no species in common (probably only *Atrypa reticularis* and *Leptodesma rhomboidea*). *Chonetes cornutus,* which at Rochester and Sodus always occurs on the same slabs as Monograptus and Retiolites, is already listed as upper Clinton by Bassler (13: 1487), as also Monograptus.

The transfer of the true Williamson to the upper Clinton makes but inconsequential changes in Bassler's lists. *Monograptus clintonensis* and perhaps *Plectambonites transversalis* (that is, *P. elegantulus*) are erased from the lower Clinton, while *Leptodesma rhomboidea* is added to the upper Clinton. *Retiolites venosus* and *"Rhynchonella"* (*Camarotœchia*) *emacerata,* with possibly *Lingula* (*Palæoglossa*) *perovata,* are also removed to upper Clinton. In addition to these the following have been inadvertently admitted to the lower Clinton list and must be transferred to the upper Clinton-Rochester independently of the rectification of boundaries here proposed: *Atrypina disparilis* and *Nucleospira pisiformis* of the Rochester shale at Wolcott village and many other localities, *Cyrtia meta* of the upper Irondequoit and Rochester, *Pentamerus ovalis* and *Lingula tœniola* of the Phœnix-Herkimer, *Palæophycus striatum* of the Brewerton, and probably also *Kionoceras* (*sub*)*cancellatum* of the Irondequoit and Rochester. *"Holopea fragilis"* should read *Helopora.*

While the dividing line between lower and upper "Clinton" thus grows more clear cut, that between "Medina" and "Clinton" since the discovery of the Medina age of the so-called Clinton of Ontario (Cataract) and Ohio (Brassfield) correspondingly fades away. The same argument that would include the Rochester shale in the upper Clinton would embrace the Medina (excluding Queenston) in the lower Clinton. Neither one is present in the type "Clinton" section. But faunally the affinities named are unquestionably great, emphatically greater than those between lower and upper "Clinton." In short, the major faunal and stratigraphic break within the Eontaric is at the Wolcott Furnace ore and cleaves the "Clinton" into two parts, one of which falls naturally into company with the Rochester and the other with the Cataract-Medina, though each still retains a minor individuality from either of these. The name Clinton, like the "Silurian" of older writers, has been doing double duty.

The writer is not prepared to offer names for the combined "Lower Clinton"-Medina and the "Upper Clinton"-Rochester, respectively lower and upper Eontaric. Preferably these names should come from the thick sections in Pennsylvania or Maryland. But it is interesting to note that the four chief divisions now outlined (approximately Medina, lower

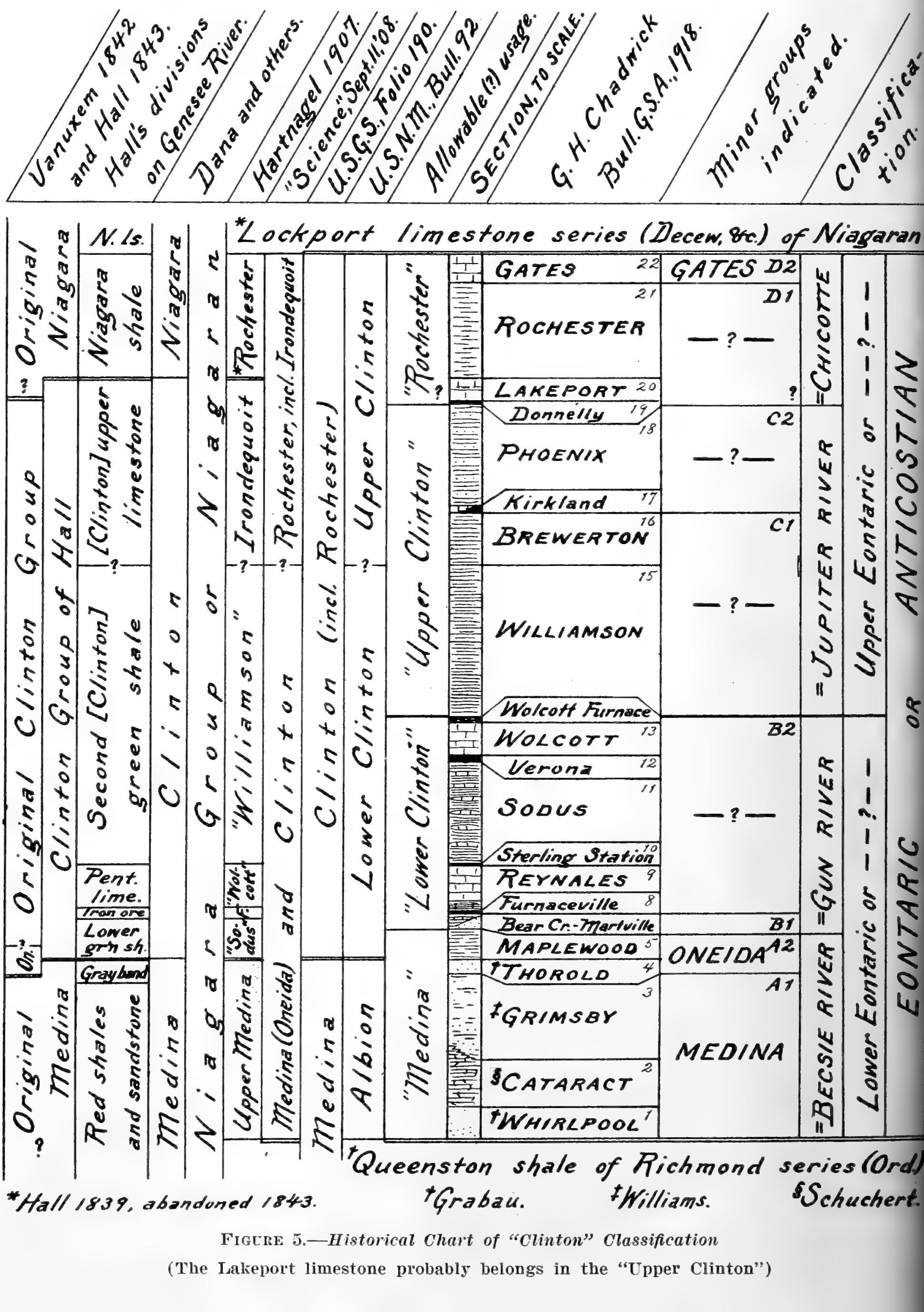

FIGURE 5.—*Historical Chart of "Clinton" Classification*

(The Lakeport limestone probably belongs in the "Upper Clinton")

Clinton, upper Clinton, and Rochester) are closely paralleled by the four Silurian divisions of the Anticosti series (13, plate 4, omitting Gamachian), and that the term *Anticostian* is indeed the best available series name for the Eontaric as here defined.

The chart (figure 5) will serve to express the present summation of the problem of the New York "Clinton" and its associate strata. The section is based on the thicknesses given in a preceding list of horizons. The columns on the left show the main steps in the nomenclatural history and those on the right the writer's conception. Under the caption "Allowable (?) usage" is a possible compromise or transitional terminology entailing the least displacement of familiar terms, though such a Procrustean solution is not wholly unobjectionable.

Conclusion

The New York "Clinton" holds but the thin overlapping edges of the more wide-spread members of the strata which in Pennsylvania are reputed to be nearly half a mile thick.[21] Between these rhythmic waves of submergence must be many disconformities in the strata, especially in the basal ones, which (when marine) should be thin and non-persistent as compared with the higher.

Though thus fragmentary, the New York record is perhaps the more valuable for purpose of classification, since it isolates and emphasizes successive faunules that in areas of continuous sedimentation may so blend or overlap as to obscure their systematic value.

The section at Clinton was a most unfortunate one on which to base a name for a group, as its elements have long remained undifferentiated, are largely lacking in discriminative criteria, and are far from typical for nearly every component.

The faunal characterization of the group had to be made from other localities lying beyond a wide drift-covered interval, beneath whose veil the lithology and fossils change so completely that the original correlation was scarcely more than a "good guess," fortunately now justified by the well records.

But the "Clinton group" as generally interpreted proves to consist of two incongruous portions, belonging one with the Rochester, the other with the Cataract-Medina. Hence, since the name "Clinton" can not without much inconvenience be extended to embrace these last, and so to cover the whole Eontaric (Anticostian), nor can it well be restricted to either of its two components, as was done with the name Silurian, it would ap-

[21] Professor Schuchert comments that a lot of this is Salinan.

pear logical to gradually eliminate it by substituting a name for each half. It is not expected that this step, or indeed any of the changes herein proposed, will be adopted without full discussion (see Science, new series, volume 39, 1914, footnote to page 918) and much further field-work, particularly in the eastern area. The proposals must be considered tentative, opening the way to restudy of the whole problem.

Paleontologic Summary

In order to complete the faunal lists, the following names are applied to some of the "fucoids" described without names by Hall (3):

Arthraria dicephala, nom nov., for New York Paleontology, volume 2, plate 10, figure 6.
Conostichus? medusa, nom nov., for New York Paleontology, volume 2, plate 7, figure 2.
Conostichus? polygonatus, nom nov., for New York Paleontology, volume 2, plate 10, figures 9, 10.
Conostichus? circulus, nom. nov., for New York Paleontology, volume 2, plate 10, figure 4.
Dactylophycus pes-avis, nom. nov., for New York Paleontology, volume 2, plate 10, figure 3.
Palæophycus bacterium, nom. nov., for New York Paleontology, volume 2, plate 9, figure 4.

Sphyradoceras? malti, sp. nov., is used without description for a new form of considerable beauty from the Clinton drift boulders at Clarendon that have afforded also a handsome new Goldius. The descriptions of these and other new forms obtained from our Silurian strata are deferred to a later publication.

The following combinations believed to be new are used herein:

Aristophycus? heterophyllum (*Fucoides heterophyllus* Hall).
Aristophycus? cf. *heterophyllum*, for New York Paleontology, volume 2, plate 8, figure 4.
Asterophycus? palmatum (*Buthotrephis palmata* Hall, plate 6, figure 1).
Atrypa reticularis affinis (*Atrypa affinis* Vanuxem, not Sowerby?).
Blastophycus? impudicum (*Buthotrephis impudica* Hall).
Botryocrinus plumosus (*Glyptocrinus plumosus* Hall).
Camarotœchia? bidens (*Rhynchonella bidens* Hall).
Camarotœchia? emacerata (*Rhynchonella emacerata* Hall).
Chondrites? ramosus (*Buthotrephis ramosa* Hall).
Cœlospira nitens (*Orthis nitens* Vanuxem; *Atrypa hemispherica* Hall, not Sowerby?).
Cycloceras "imbricatum" (*Orthoceras imbricatum* Hall, *not* Wahlenberg). Wahlenberg's species is an Actinoceras, according to Foord.
Cyclora? subulata (*Murchisonia subulata* Hall pars, figure 7*a* only).

Cyclostomiceras? abruptum (*Orthoceras abruptum* Hall).
Dactylophycus? sp., for New York Paleontology, volume 2, plate 8, figure 5.
Dawsonoceras americanum (*Orthoceras annulatum americanum* Foord). Clearly distinct from the type of *D. annulatum*, but possibly not from *Dawsonoceras nodocostatum* (McChesney).
Eophyton? striatum (*Palæophycus? striatus* Hall).
Kionoceras subcancellatum (*Orthoceras cancellatum* Hall preoc., *O. subcancellatum* Hall in Miller).
Palæoglossa acutirostris (*Lingula acutirostra* Hall).
Platystrophia brachynota (*Delthyris brachynota* Hall).
Plectambonites elegantulus (*Strophomena elegantula* Hall; *Leptæna sericea* Hall: New York Paleontology, volume 2, page 59).
Pterinea leptonota (*Avicula leptonota* Hall).
Rafinesquina clintoni (*Strophomena clintoni* Vanuxem; *Leptæna obscura* Hall).
Rafinesquina corrugata (*Strophomena corrugata* Conrad).
Schellwienella? subplana (*Strophomena subplana* Conrad).
Semicoscinium clintoni (*Retepora clintoni* Vanuxem; *Fenestella prisca?* Hall, not Lonsdale).

Important Papers

The following list includes only those of prime importance in the study of New York Clinton stratigraphy:

(1) 1842. LARDNER VANUXEM: Geology of the Third District, New York.
75-78, Oneida conglomerate.
79-90, Clinton group.
257, 262, 272, County reports.

(2) 1843. JAMES HALL: Geology of the Fourth District, New York.
58-79, Clinton group.
81-83, 97, 100-117, Niagara shale.
414, 422, 433, 440, County reports.

(3) 1852. JAMES HALL: Paleontology of New York, volume 2.
15-17, Clinton group, strata.
18-105, 179-184, 297-301, 353, Clinton fossils.
106-108, Niagara group.
109-176, 185-295, 302-320, 351-353, Niagara fossils.

(4) 1898. F. J. H. MERRILL: Guide to the geological collections of the New York State Museum, Bulletin 19.
153, 190, 219, Clinton group.
Plates 44, 49-57, Views of Clinton sections.

(5) 1901. AMADEUS W. GRABAU: Geology and paleontology of Niagara Falls. New York State Museum, Bulletin 45.
95-102, Clinton beds.
102-105, Rochester shale.
130-228, Fossils of the Niagara region.

(6) 1902. F. J. H. MERRILL: State geologic map of 1901. Bulletin 56, New York State Museum, opposite page 34, Comparative table of geologic nomenclature.

(7) 1907. Chris A. Hartnagel: Stratigraphic relations of the Oneida conglomerate, in Bulletin 107, New York State Museum, pages 29-38.

(8) 1907. C. A. Hartnagel: Geologic map of the Rochester quadrangle.
12-17, Clinton formation.
17-19, Niagara formation, Rochester shale.

(9) 1908. D. H. Newland and C. A. Hartnagel: Iron ores of the Clinton formation in New York State. Bulletin 123, New York State Museum.

(10) 1913. E. M. Kindle and F. B. Taylor: Niagara Folio number 190, United States Geological Survey.
6-7, Clinton formation.
15-16, Silurian period.

(11) 1914. T. C. Hopkins: Geology of the Syracuse quadrangle. Bulletin 171.
7-8, Clinton-Rochester shales.
57-58, Fossils from the Niagaran formations—Burnett Smith.

(12) 1914. Charles Schuchert: Medina and Cataract formations. Bulletin of the Geological Society of America, volume 25, page 277.
292-293, Contact with Medina.
296, Summary of sections.
304-316, Sections in detail.

(13) 1915. Ray S. Bassler: Index of American . . . Silurian fossils. Bulletin 92, United States National Museum.
1486-1489, Faunal lists of New York Clinton.

Postscript

The writer desires also to thank Dr. Burnett Smith for the privilege of examining the collections from Brewerton, Phœnix, and near Three Rivers Point. These confirm the deductions above made. The faunas, partly new, are being studied for publication by one of Doctor Smith's students.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

SCOPE AND SIGNIFICANCE OF PALEO-ECOLOGY

BY FREDERIC E. CLEMENTS [1]

(Read before the Paleontological Society January 2, 1918)

CONTENTS

THE PROVINCE OR FUNCTION OF ECOLOGY

At the outset it seems desirable to emphasize the view that ecology is not a new division of biology, or indeed a division at all. It is merely a point of view, a new method of attack, which has been as natural a rebound from the intensive laboratory research of the last twenty-five years as this was a logical reaction from the more diffusive studies of natural history. The viewpoint of ecology inheres in the "oikos," or habitat, as the motive force in the life processes of plants and animals, both as individuals and as communities. As a consequence of this vital relation ecology is essentially synthetic. It is deeply concerned with soil and climate, but never as ends in themselves, merely as intrinsic parts of basic biological processes. While the ecologist can not ignore the static forms of plant and animal life, he is interested in them chiefly as the end-forms of responsive processes. In short, ecology deals primarily with processes and is inherently and universally dynamic. This means that it should be experimental in the highest degree, and that development is the one great clue which it must follow throughout. As a result, it must be quantitative in method, beginning with the habitat in which measurements are relatively simple, and running through individual and community responses in which they are difficult. Further, the name itself

[1] Manuscript received by the Secretary of the Society March 7, 1918.

makes it clear that living things and processes are to be studied first and last in the oikos, or habitat—whether forest, prairie, desert, or cultivated field—though with the fullest use of controls wherever these are necessary or desirable. Finally, the method of the ecologist must be at the same time intensive and extensive if he is to follow processes accurately and to apply them broadly.

The Utilization of Ecology

It is perhaps puzzling to understand how the demands of ecology can be met in a field where processes have ceased. The readiest answer, and a fairly complete one, is afforded by the principle of uniformity of processes, the use of which has made modern geology possible. The value of this principle has recently been recognized in climatology, and it is also proved to be of wide application in plant succession. The initial use of it in succession has met with such success as to suggest its wide application in the whole field of paleo-ecology. As a consequence, it has become clear that the development of the ecological aspects of paleontology must depend absolutely on the progress of present-day ecology. In just the degree that the latter becomes synthetic, experimental, and quantitative will it be possible to apply it accurately and thoroughly to the interpretation of past life processes. In this connection there is no thought of minimizing the ecologic contributions of paleontology; but these have usually been a by-product of taxonomic, phylogenetic, or stratigraphic studies, and their ecological orientation has been difficult or uncertain.

Synthetic Character of Paleo-ecology

It is assumed that paleo-ecology must be primarily synthetic; that it must deal chiefly with processes, their development and correlation. In fact, the latter stand out in bolder relief because the phenomena are fewer and more isolated. Moreover, special fields have not been differentiated in it, and it is possible to follow sequences through without stopping at artificial boundaries. This is especially significant at a time when the conviction is slowly growing among ecologists that the life of a habitat must be studied as a unit complex and not in two detached parts. The feeling that correlation is the paramount method leads to the realization that it must be based on natural and hence causal sequences. This is what is meant by saying that the clue to ecology is found in the habitat. The latter is the complex of causes or of factors which act on the plant and the animal; but the habitat acts directly on plants, while it affects land animals for the most part indirectly through the food and shelter control exerted by plants. As a consequence, the plant may be looked on

as the middleman between the habitat and the animal life. It is an effect to the one and a cause to the other. It is obvious that the total relation is far more complex than this, since factors do act directly on animals as well; but it must be granted that the study of plants and plant communities does enable us to look in both directions—that is, back to the physical factors of the habitat and forward to the animal responses. In addition to this basic causal sequence is the resulting reaction sequence in which animals react on plants and plants on soil and climate, to say nothing of the direct action and reaction between habitat and animals. In emphasizing the primary value of sequences, there is no need to assume that plants are the most important part of paleo-ecology because of their strategic medial position. They do, however, afford the best points for entering this vast field.

Methods of employing previous ecological Results

The methods by which the ecological results of today can be carried back into the past have been briefly discussed in "Plant Succession" and it will suffice to pass them in review here. For the most part these are methods with which the paleontologist is already familiar, since they have to do primarily with the translation of facts from the present to the past. The foremost is the method of causal sequence, already mentioned, with its basic relation of habitat, plant, and animal. This is well illustrated by the occurrence of Stipa in the Miocene of Florissant, which indicates not merely the existence of prairie, but also, of course, a grassland climate and a grazing population. A similar but even more fundamental sequence begins with deformation and passes through gradation, climate, and vegetation to exhibit its final effects in the fauna. The method of phylogeny which has been the most serviceable of taxonomic tools is likewise of great value in the reconstruction of the life forms and communities of the past. It shares with the method of succession the credit of permitting us to give more and more detail to the bold outlines of past vegetations and vegetation movements. The method of succession is based on the great strides made by the developmental study of vegetation during the last twenty years. When successional studies become the rule in zoo-ecology as well, there will seem to be no limit to the increasing perfection of detail in picturing the rise and fall of past populations and communities. In the case of vegetation, this method has already gone so far as to bring conviction that all the essential features of successional processes and climax communities as seen today already existed in the past. As indispensable corollaries of the methods of phylogeny and succession are inferences from distribution in

space and in time and from association. The former enables us to close many a gap in the fossil record and to fill in the areas outlined by the known distribution of dominants. Inference from association, for example, aided by phylogeny, makes it all but certain that swamps of reed-grass, bulrushes, and cattails existed as far back as the Cretaceous, though Phragmites is the only one of the three dominants recorded for that period.

The most recent is the method of cycles which gives promise of becoming one of the most important. It is perhaps too soon to insist that cyclic processes are universal in time and in space; but the great mass of evidence from geology and climatology is matched by an increasing body of facts from biological succession. The most fertile of all these assumptions is that climatic changes recur in cycles of various intensity and duration. It is a matter of congratulation that climatic cycles can be studied by their effects almost as well in the past as in the present. This is particularly true in peat bogs and in badlands where fossil trees, alternating or recurring deposits, and cycles of erosion furnish a wealth of virgin material. Fossil wood is fortunately of the widest occurrence, and it is proposed to study the annual rings of fossil trees from those of recent peat bogs back through the Pleistocene and Tertiary into the later Mesozoic. Preliminary studies in the Pleistocene, Miocene, and Eocene already suggest the existence in these periods of a sun-spot cycle identical with that demonstrated by Douglass, Huntington, Kapteyn, and others in the trees of today. Similar cycles seem to be recorded in the rings of sagebrush, saltbush, and other desert shrubs, and these have been used in studying shifting cycles of erosion in badlands.

Like its modern representative, paleo-ecology must focus its attention on the three great and interrelated problem complexes, namely, the habitat, the biotic community, and the development of the latter. While it comes first causally, the habitat actually must wait on biological interpretation, as its biological effects are about all that remain of it. Thus it becomes the biome, or mass of plants and animals of a particular area or habitat, on which attention must first be fixed. The direct outcome of this is to reveal the successional movement, and on this as well as on the adaptive features of species and genera must be based our assumptions as to geological climates and soils.

In phytoecology the concept advanced in 1901, that the plant community is a complex organism, with structure and functions and with a characteristic development, appears to be slowly making its way. The admission of animals into the community with full rights and privileges promises to open a new period in synthetic ecology. In paleo-ecology the concept of the biome, or biotic community, seems to have peculiar value, as it directs especial attention to the causal relations and reactions of the

three elements—habitat, plant, and animal. Fortunately this viewpoint is so new that there are no landmarks or traditions to handicap. It is possible to deal with causes and reactions from a single vantage ground of developmental processes. As already stated, the plant community appears to have unique advantages in tracing the concomitant development of habitat and biome and in determining the structural responses of the latter. Here, again, ecology is fortunate in that zoologists have but recently turned to the development and structure of animal communities. It is thus necessary to follow the causal sequence and to base the treatment primarily on vegetation as the effect of habitat and as a cause in relation to animal communities. The opportunity is also given to test the successional method of vegetation study in its application to development when animals are regarded as an intrinsic part of the community. This application has already begun both in ecology and paleo-ecology, and this use of successional methods gives every promise for the future.

The developmental method is based on the universal fact that bare areas of rock, soil, or water, and areas denuded of vegetation by fire, cultivation, erosion, etcetera, become occupied by pioneer plants and animals. These react on the habitat in such a way as to change it in favor of organisms of greater requirements, which then invade and replace the pioneers. This process of reaction and successive invasion continues through more or less definite stages until a final population appears and the climax is reached. The climax once reestablished will maintain itself indefinitely unless a change of climate occurs or the climax is destroyed wholly or in part as a result of external forces. One of the most familiar examples of such a unit succession, or sere, is afforded by a pond or lake in which the submerged plants and associated animals are gradually replaced by floating plants, and these in succession by reeds, sedges, grasses, and scrub, until, in a forested region, the final forest is reached. Similar cases of biotic succession occur in dunes, badlands, lava flows, burns, fallow fields, etcetera, throughout the world. Similar seres also must have been abundant throughout geological periods since the Devonian, at least, except for those due to the agency of man. For certain periods, such as the Pleistocene in particular, the Miocene, and the Triassic, the plant remains have recorded the unit successions beyond any question. This is most graphically shown in the peat bogs of Scandinavia and Britain, where two or three successive seres have left a complete record of their plants. Such a successional series may be termed a cosere. It is of the first importance in connecting succession in the present with the same developmental process in the past, and hence in putting the successional study of paleo-ecology on a firm basis. The peat cosere furnishes the best evidence of population shifting through climatic changes, and

provides an assured method for the reciprocal correlation of climatic changes and biotic movements in the past. These are involved in still greater successional movements having to do with the appearance of new biomes and the disappearance of preceding ones. The grand succession of the globe falls readily into four great successions characteristic of the four eras. In each era occurred major successional shifts which consisted, in turn, of coseres and seres, such as are capable of actual study today.

The Attack on developmental Correlation

In planning an attack on the developmental correlation of plant and animal communities in the past as well as in the present, the badlands of the West early suggested the most promising field. A badland is an extremely dynamic area, scarcely excelled by dunes in this respect. It is one in which the rapid changes in habitat are clearly reflected in the development of the biotic community. In addition they afford a unique chance to relate minor cycles of erosion to climatic cycles and to fix the dates of these cycles by means of the annual rings of the characteristic shrubs. As is well known, the badlands are not only classic ground for the paleontologist, but they also furnish a practically complete series from the Permian through the Miocene. This series embraces practically the whole panorama of terrestrial life and affords an exceptional opportunity for organizing the vast field of paleo-ecology. The recognition of these facts has led during the past four years to an intensive study of twenty or more badland formations in seventy-five localities in twelve States. All the major areas have been visited, many of them several times, and most of the minor ones as well. The most generous assistance has been accorded by paleontologists, and the results will appear as soon as the live-stock crisis in the West permits the transfer of interest from the pressing ecological problems of the present to those of the past.

Summary

To sum up, paleo-ecology is characterized by its great perspective, due chiefly to the absence of a large body of facts. This causes the fundamental correlations between the physical world and vegetation on the one hand and between vegetation and the animal world on the other to stand out in clear relief. As a consequence, paleo-ecology is an unspecialized field in which the interrelations of climate, topography, vegetation, and animals play the paramount rôle. The emphasis necessarily falls on vegetation, because it is an effect of climate and topography, and a cause in relation to the animal world, and hence serves as the keystone in the whole arch of cause and effect.

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CONTENTS

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 29, PP. 375-392 SEPTEMBER 30, 1918

PRECAMBRIAN SEDIMENTARY ROCKS IN THE HIGHLANDS OF EASTERN PENNSYLVANIA *

BY EDGAR T. WHERRY [1]

(*Presented in abstract before the Society December 28, 1916*)

CONTENTS

INTRODUCTION

Precambrian rocks are exposed in Pennsylvania in three belts—the South Mountain belt, which is a northward extension of the Catoctin belt of Maryland and terminates a few miles southwest of Harrisburg, owing to covering by Paleozoic and Mesozoic sedimentary rocks; the Piedmont belt, which extends from the Maryland line at the Susquehanna River

* Manuscript received by the Secretary of the Society December 13, 1917.

[1] The greater part of the work herein described was done while the writer was teaching at Lehigh University. It was completed during his connection with the U. S. National Museum. The paper was presented in abstract at the meeting of the Geological Society of America December 28, 1916; an abstract was printed in Bull. Geol. Soc. Am., vol. 28, 1917, p. 156.

through the northern part of the city of Philadelphia to the Delaware River at Trenton, New Jersey, where it is likewise covered by later sediments; and the Highland belt, which emerges from beneath the sedimentary cover 40 miles east of Harrisburg, and at Easton crosses the Delaware River into New Jersey, where it broadens to form the Highlands. The last belt, to which attention is especially directed in this paper, is about 60 miles long and attains a maximum width of 20 miles in this State.

Henry D. Rogers, first State Geologist of Pennsylvania, regarded the Precambrian rocks of all of these belts as dominantly sedimentary in origin, stating:[2]

"The strata upon which the surface-wash and soils of Pennsylvania repose belong to the three oldest classes of the sedimentary rocks—namely, to the gneissic, the Paleozoic, and the earliest Mesozoic. . . . No large masses of igneous or volcanic rocks of any description appear within the borders of the State." . . .

J. Peter Lesley, the second State Geologist, evidently held the same view, for in his chapter, "Are the Archean rocks sedimentary?" [3] he discussed the banded structure of the gneisses and their intimate association with crystalline limestone and supposedly sedimentary serpentine and iron ore, and presumably concluded that the gneisses are in general of sedimentary origin, without so stating directly.

In late years, however, the tendency has been to interpret the gneisses of the Highlands of New Jersey, and correspondingly of the adjacent Pennsylvania belt, as of dominantly igneous origin, as illustrated by three folios.[4] The presence of Precambrian sediments, represented by the Franklin limestone and certain of the gneisses, was also recognized in these folios, as well as in a separate paper by Professor Bayley.[4a] Some of the occurrences in the New Jersey Highlands, referred to in that paper, are evidently very similar to those in the Pennsylvania area here described.

More recently it has been pointed out by Dr. C. N. Fenner[5] that the banding of some of the supposedly primary gneisses is of such a character "that their origin must be looked for in a process involving the injection of a thinly fluid granitic magma between the layers of an original rock of laminated structure."

[2] Geology of Pennsylvania, vol. i, 1858, p. 59.

[3] Summary Final Report, Second Pennsylvania Geological Survey, vol. i, 1892, pp. 95-117.

[4a] W. S. Bayley: Rept. 12th Int. Geol. Congress, 1913, p. 334.

[4] A. C. Spencer, W. S. Bayley, and others: U. S. Geological Survey, Passaic, Franklin Furnace, and Raritan Folios, Nos. 157, 161, and 191, 1908-1913.

[5] Journal Geology, vol. 22, 1914, pp. 594-612, 694-702.

Between 1908 and 1913, while connected with the geology department of Lehigh University, which is situated in South Bethlehem, Pennsylvania, on the north flank of this belt, the writer made a study of the Precambrian rocks of that vicinity.[6] High-alumina mica-schists, such as are common in the Piedmont belt, but had not been previously reported from this northern one, were discovered at a number of widely separated points, and evidence was obtained which strongly confirms Doctor Fenner's conclusion that the banding of a by no means inconsiderable proportion of the gneisses is a remnant of original lamination.

General Geology

The rocks of the region which are believed to be of sedimentary origin are crystalline limestone, quartz-mica schist, graphite-bearing quartzite, the gneisses derived from the last two by magmatic action, and basic (amphibolitic) gneiss. The limestone is thought to be the exact equivalent of the Franklin of New Jersey, while the other rocks are regarded as representing sediments of diverse character which were deposited more or less contemporaneously with the limestone. The areas occupied by these rocks are approximately as follows, in square miles:

Crystalline limestone	0.5
Quartz-mica schist and derived gneiss	5.5
Graphite-bearing quartzite and gneiss	9.0
Basic (amphibolitic) gneiss	35.0
Total (about one-tenth of the area of the belt)	50.0

Subsequent to the deposition of these sediments the region was invaded by igneous magmas, the sedimentary formations being extensively metamorphosed and no doubt partly assimilated. Five igneous formations can be recognized—granitic gneiss, the Byram of New Jersey, made up chiefly of quartz and orthoclase or microperthite feldspar; dioritic gneiss, the Losee of New Jersey, similar to the preceding, but containing considerable plagioclase feldspar; gabbroic gneiss, the igneous portion of the New Jersey Pochuck, high in augite and containing basic plagioclase; granitic pegmatite; and diabase.[7] All of these formations are overlain unconformably by the basal Cambrian quartzite.

[6] While most of the data presented herein were obtained on the Allentown quadrangle, in which South Bethlehem is located, a few visits to the southwestern extension of the belt on the Boyertown and Reading quadrangles showed the formations there to be identical. No detailed studies were made by the writer of the Precambrian in these two quadrangles, because this was to be mapped by Misses Bliss and Jonas, under the direction of Miss Bascom; that mapping has since been completed.

[7] Described by Anna I. Jonas: Bull. Am. Mus. Nat. Hist., vol. 37, 1917, pp. 173-181.

In the following table average counts of the areas occupied by the various constituent minerals in thin sections of the first three igneous formations are presented for comparison with the tabulations of the sedimentaries below:

TABLE 1.—*Mineral Compositions of igneous Rocks*

	1 Granitic gneiss	2 Dioritic gneiss	3 Gabbroic gneiss
Quartz	30	25	5
Feldspars:			
Orthoclase	15	15	5
Microperthite	40	..	..
Oligoclase-andesine	5	40	..
Andesine-labradorite	..	..	40
Accessories	10	20	50
Including:			
Augite	x	x	x
Hornblende	x	x	x
Enstatite-hypersthene	..	x	x
Biotite	x	x	x
Minor minerals	x	x	x

Crystalline Limestone

CHARACTER

The limestone is normally a faintly stratified, coarsely crystalline rock, containing apatite, diopside, graphite, phlogopite, titanite, tremolite, and

FIGURE 1.—*Crystalline Limestone showing Alteration to Amphibolite.* (× ½)

Locality, 3 miles north of Boyertown, Pennsylvania. The portion below and to the left is completely altered, and isolated grains of amphibole are growing in the midst of the gray limestone above.

other accessory minerals, and locally secondary serpentine and talc. It shows interdigitation with all of the other sedimentary formations.

Where it has been acted on by intrusive magmas the limestone has been considerably metamorphosed, minerals of the amphibole and pyroxene groups having been developed in large amounts. In some cases small bodies of amphibolite and pyroxenite with gneissoid texture have formed, the calcium carbonate having completely disappeared (see figure 1). Further details need not be given here, as typical occurrences of this formation have been described in reports of the Pennsylvania Topographic and Geologic Survey Commission.[8]

ORIGIN

Assignment of a sedimentary origin to this limestone needs no justification.

Quartz-mica Schist

CHARACTER

This formation is typically a pale greenish gray rock composed of flattened lenses of quartz separated by films of sericite mica, through which extend blades of sillimanite. A specimen is shown in figure 2. This grades on the one hand into quartzite by the disappearance of the

Figure 2.—*Quartz-mica Schist with Sillimanite.* (× ½)

Locality, 1 mile north of Springtown, Allentown quadrangle. Specimen 9243. The sillimanite appears as white blades against the brownish gray quartz; the upper part of the specimen is stained red—which appears dark in the photograph—by iron oxide resulting from the decomposition of pyrite.

mica, and on the other into muscovite-schist as the quartz diminishes and the mica becomes more coarsely crystalline. In addition to the sillimanite several other minerals are occasionally present as accessory constituents, and may locally become abundant; the most frequent are apatite, biotite, garnet, ilmenite, pyrite, tourmaline, and zircon.

---

[8] Frederick B. Peck: Preliminary report on the talc and serpentine of Northampton County. Topographic and Geological Surv. Penna., Rept. 5, 1911, pp. 12-23; Benj. L. Miller: Graphite deposits of Pennsylvania. Ibid., Rept. 6, 1912, pp. 75-76.

As this formation has not been recognized heretofore[9] certain of its features may be described in greater detail. In thin section the quartz occurs in interlocking grains, showing marked wavy extinction and often traversed by sericite-filled cracks. The mica has the usual flaky structure, its crystals varying from submicroscopic size (pinite) through the minute grains of sericite to the coarse plates of muscovite. The sillimanite occurs in long slender prisms, mostly curved or bent slightly and in subparallel arrangement; it is easily recognized by its high relief, medium double refraction, straight extinction, and positive sign. Many of its crystals exhibit a mesh structure resembling that of serpentinized olivine, owing to alteration into pinite along cracks; this is well shown in figure 3. The garnet varies considerably in amount and form, crystals 1 centimeter in diameter, filled with inclusions of quartz and mica, being sometimes found, although it is usually much smaller. A thin section of one of these, with typical inclusions, is shown in figure 4. In color it is always pink or pale red. The zircon occurs in minute grains inclosed in the quartz mosaic; and these are usually rounded in outline, as shown in figure 5, in marked contrast with the angular outlines of crystals from the igneous rocks of the region, one of which is illustrated in figure 6.

Counts of the areas occupied by the various minerals in typical thin sections gave the results set forth in table 2:

TABLE 2.—*Mineral Composition of the Quartz-mica Schist*

	1	2	3	4
Quartz	55.4	52.6	49.7	50
Sericite	5.9	40.0	15.7	20
Sillimanite	35.1	6.8	24.3	25
Accessories	....	....	.....	5
Feldspar (altered)	....	0.4	5.0	...
Biotite	1.6	0.1	....	...
Ilmenite	1.95	0.05	....	...
Pyrite (and limonite)	....	.....	5.2	...
Zircon	0.05	0.05	0.05	...
Apatite	.....	.....	0.05	...
Totals	100.00	100.00	100.00	100

The specimens, on sections of which the above counts were made, were collected at widely separated points on the Allentown quadrangle, as follows:

1. One mile west of Seidersville (206).
2. Two miles southeast of Freemansburg (217).
3. East edge of quadrangle, one mile south of Lehigh River (6396).
4. The rounded-off average of 1, 2, and 3.

[9] In the Raritan, New Jersey, folio several schistose rocks were noted to occur in the Precambrian, but they appear to be somewhat different from the material here described. However, similar rocks are described in New Jersey in a forthcoming report on the Delaware Water Gap quadrangle.

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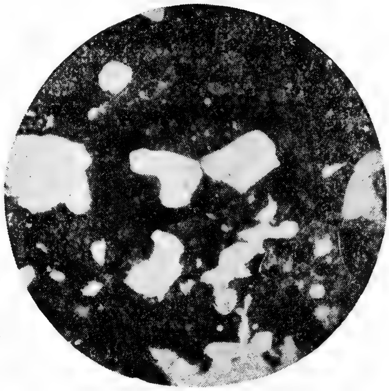

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FIGURE 3.—*Photomicrograph of Quartz-mica Schist with Sillimanite. × Nicols.* (× 20)

Locality, 1½ miles northeast of Mountainville, Allentown quadrangle. Specimen 7323. The sillimanite shows mesh-structure owing to alteration to pinite along transverse cracks; the bulk of the field is occupied by sericite, with a few irregular grains of quartz.

FIGURE 4.—*Photomicrograph of Quartz-mica Schist with Garnet. Ordinary Light.* (× 20)

Locality, 1 mile north of Springtown, Allentown quadrangle. Specimen 253. The bulk of the field is occupied by garnet; it contains numerous inclusions of clear quartz and a few mottled gray patches of micaceous material.

FIGURE 5.—*Photomicrograph of Quartz-mica Schist showing rounded Zircons. Ordinary Light.* (× 100)

Locality, east edge of Allentown quadrangle. Specimen 6396. The clear pale gray areas are quartz; the Y-shaped mass in the center is sericite; round zircons of all sizes standing out in relief are to be seen around the right-hand arm of the Y.

FIGURE 6.—*Photomicrograph of Granite, showing angular Zircons, for Comparison. Ordinary Light.* (× 100)

Locality, ridge southeast of Lower Saucon, Allentown quadrangle. Specimen 6866. Two attached zircon crystals appear near the center; they show distinct angular outline.

A partial chemical analysis of a sample from specimen 1 in the above table gave: SiO_2, 67.4; Al_2O_3 (including Fe_2O_3, TiO_2, and ZrO_2), 29.9; alkaline earths, alkalies and water, by difference, 2.7 per cent.

ORIGIN

Quartz-sericite schists may so readily be formed by the shearing of igneous rocks that it seems worth while to discuss at some length the evidence from which the sedimentary origin of the present rock is inferred.

The abundance of quartz and the high content of both silica and alumina shown by analysis are characters more commonly associated with sedimentary than with igneous formations. The relatively large amount of well defined crystals of sillimanite is also regarded as a good indication of the sedimentary origin of the rock, for this mineral, while not unknown

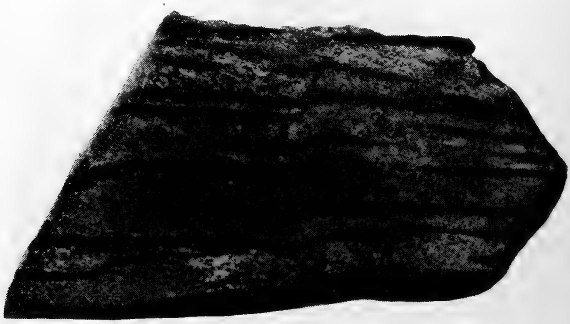


FIGURE 7.—*Quartz-mica Schist showing Invasion by Granite.* (× ¼)

Locality, 2 miles southeast of Freemansburg, Allentown quadrangle. Specimen 6493. The dark layers of the schist are being separated by the paler granite, but retain approximate parallelism.

as a constituent of igneous rocks, is far more characteristic of metamorphosed shales, originally high in aluminum minerals, such as kaolin. Large round garnets with pale colors and abundant inclusions, such as occur here, are also most frequently found in metamorphosed sediments. The presence of numerous well rounded grains of zircon in a rock is, as pointed out by Trueman,[10] strong presumptive evidence of sedimentary origin; and this feature is typically shown in the present rock.

From the structural viewpoint, the evidence of the sedimentary origin of this formation seems equally conclusive. The repeated alternation of laminæ high and low in silica and the extension of the lamination in straight lines for long distances, both of which features it shows, are characteristic of sediments. But the most significant relation is that

[10] Journ. Geol., vol. 20, 1912, p. 257.

shown toward the igneous rocks of the region, which is discussed in the following paragraph.

The quartz-mica schists are frequently in contact with granite, and in every case the field relations show that the latter is the subsequent rock. It either cuts across laminæ or forces them apart, giving rise to banded rocks, such as the ones illustrated in figures 7 and 8. On the other hand, sheared granites, observable at several places in the region, present a totally different picture. The quartz and feldspar grains show progressively undulatory extinction, then shattering, a good example of which is shown in figure 9, then alteration to sericite, the final result being a pseudo-porphyritic mass of compact sericite with wavy and irregular lamination, dotted with rounded fragments of the original constituents.

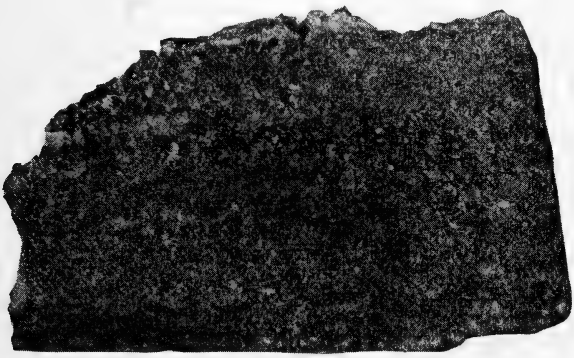


FIGURE 8.—*Quartz-mica Schist showing Invasion by Granite.* (× ½)

Locality, 5 miles west of Boyertown. The layers of schist at the bottom are contorted, and have evidently been practically melted by the granite, which permeates them.

These rocks are the opposite of the quartz-mica schist in every respect. Quartz is small in amount, sillimanite and garnet absent, and zircon angular. Across the lamination the variation is gradual; along the strike rapid. And the igneous rock grades into the schist, never cutting sharply across nor penetrating it along laminæ.

MAGMATIC MODIFICATION

As far as can be determined, feldspar is absent or present only in very subordinate amount in the normal schist. But where emanations from the granite magmas have acted on the rock, feldspar has been extensively introduced; it is chiefly orthoclase showing microperthitic intergrowth of oligoclase. This feldspar impregnates the rock more or less uniformly, surrounding the grains of the normal constituents. The laminæ may be but slightly separated, moderately deformed, and obscured to a negligible

degree, as in the specimen illustrated in figure 7. Here feldspathization must have been produced by thinly fluid emanations from the magmas. In other instances the laminæ may be spread widely apart, more or less strongly deformed, and their identity largely destroyed; an instance of this is shown in figure 8. At one locality where the magmatic material was pegmatitic in character rude crystals of sillimanite as much as 1 centimeter in diameter and 3 centimeters long have been observed, the blades of this mineral in the adjoining schist being, on the other hand, rarely one-tenth as large; the mineral must have been dissolved and recrystallized by the magma.

Counts of the areas occupied by the constituent minerals in thin sections of three of the rocks impregnated with feldspar are given here:

TABLE 3.—*Mineral Composition of feldspathized Quartz-mica Schist*

	1	2	3	4
Quartz	51.2	52.9	48.5	50
Sericite	9.8	4.0	10.0	5
Sillimanite	17.6	10.3	.....	10
Feldspars	....	.....	.....	25
Orthoclase	....	2.2	.....	...
Microperthite	18.6	23.9	30.0	...
Oligoclase	....	2.2	.....	...
Accessories	....	....	.....	10
Garnet	....	.....	8.5	...
Ilmenite	2.1	.....	.....	...
Zircon	0.05	0.10	0.15	...
Apatite	0.05	0.05	0.05	...
Miscellaneous stains, etc.	0.6	4.35	2.8	...
Totals	100.00	100.00	100.00	100

The specimens in table 3 were also collected on the Allentown quadrangle at the following localities:

1. One and one-half miles east of Mountainville (7323).
2. Two miles southeast of Freemansburg. (The same place as No. 2 in table 2.) (226.)
3. One mile northwest of Springtown (253).
4. The rounded-off average of 1, 2, and 3.

Intimately associated with the rocks above described occur finely banded gneisses which are believed to represent the extreme stage in the action of the magma on the schist. In mineral make-up these rocks are essentially identical with the igneous rocks of the region, but their ultimate sedimentary origin is indicated by the following points:

1. Close association with undoubted sediments.

2. Persistence of well developed minute lamination in straight lines for many meters.

3. Marked variation in mineral content in adjacent laminæ, as brought out in table 4.

TABLE 4.—*Mineral Composition of four successive Laminæ in a banded Gneiss*

	1 Gray	2 White	3 Gray	4 White
Quartz	40.0	51.2	45.0	40.0
Feldspars:				
Microcline (kaolinized)	56.0	18.8	46.2	32.0
Microperthite	4.0	24.4	2.0	23.6
Accessories:				
Biotite	.....	.....	6.8	2.0
Ilmenite	.....	5.5	.....	2.4
Zircon	.....	0.1	.....	....
Totals	100.0	100.0	100.0	100.0

Locality, one mile west of Seidersville, Allentown quadrangle; the same as that of specimen No. 1, table 2 (5781).

GRAPHITE-BEARING QUARTZITE

CHARACTER

Many of the features of this formation have been previously described,[11] but some will be noted here to show how analogous it is to the preceding one. The phase which can be regarded as most closely approaching the original unaltered rock is a bluish gray quartzite, made up of interlocking grains of quartz interspersed with more or less parallel flakes of graphite. The most noteworthy accessory constituents are apatite, biotite, garnet, pyrite, and zircon. In thin section the bluish hue of the quartz is often seen to be connected with the presence of included carbonaceous dust, as typically shown in the section, figure 10. Apatite and garnet are at times more prominent in this rock than they are in the quartz-mica schist. Round zircons are frequent, as in that rock. In contrast to the quartz-mica schist, however, unchanged beds are rare in the graphite-bearing formation, feldspathization having almost always taken place to a marked degree, as described below.

Table 5 presents counts of the areas occupied by the minerals in sections of three specimens of the quartzite phase.

[11] Benj. L. Miller: Loc. cit.

TABLE 5.—*Mineral Composition of Quartzite*

	1	2	3	4
Quartz	78.5	78.2	57.0	70
Graphite	10.7	21.2	0.1	10
Accessories	....	....	....	20
Biotite	....	0.5	10.6	...
Sericite	3.9	....	....	...
Feldspar, altered	0.9	....	2.2	...
Garnet	3.7	....	30.0	...
Pyrite and limonite	1.8	....	....	...
Zircon	0.05	0.05	0.05	...
Apatite	0.45	0.05	0.05	...
Totals	100.00	100.00	100.00	100

The above sections were made on specimens from:

1. One mile east of Vera Cruz station (7842).
2. Three-fourths mile southwest of Vera Cruz station, near southwest corner of the Allentown quadrangle (7788).
3. Two miles southwest of Lower Saucon (6887).
4. The rounded-off average of 1, 2, and 3.

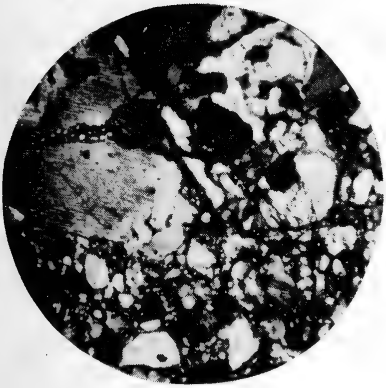
ORIGIN

The quartzitic character of this phase of the graphite-bearing formation makes its sedimentary origin seem above question. Confirmatory evidence is found in the presence of the graphite itself, in the occasional appearance of notable amounts of apatite, which may perhaps be regarded as implying the animal derivation of the carbon, and in the rounded zircons. Finally, the inferences drawn from lamination and relation with igneous rocks in the case of the quartz-mica schist hold with equal force here. The rock is totally unlike the products of shearing of the igneous rocks, both mineralogically and structurally, and shows feldspathization, injection, and assimilation by the granite rather than transition, which would result from its origin by the shearing of the latter rock.[12]

MAGMATIC MODIFICATION

Introduction of feldspar and other constituents by the invading magmas has been even more extensive in the case of this graphite-bearing formation than in that of the schist, but instead of the orthoclase and plagioclase feldspars showing microperthitic intergrowth they tend to appear separately, as brought out in the following table of mineral com-

[12] In the Raritan folio reasons are given for the assignment of an igneous origin to some of the graphite-bearing rocks, and some of the schists are believed to result from the shearing of these. No corresponding occurrences have been found in the Pennsylvania area thus far.



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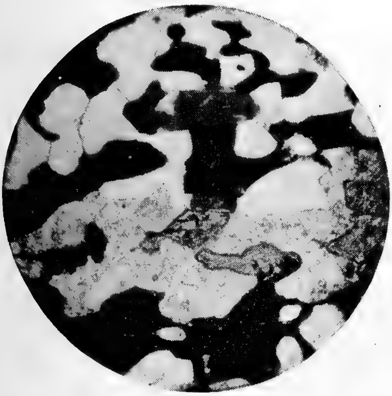

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FIGURE 9.—*Photomicrograph of sheared Granite, for Comparison with the Quartz-mica Schist.* × *Nicols.* (× 20)

Locality, 1½ miles northeast of Hellertown, Allentown quadrangle. Specimen 6749. Shows microperthite and quartz, much shattered, and surrounded by secondary micaceous material (dark) ; a large grain of perthite on the left has resisted the force, but is traversed above by a tiny fault-crack containing angular fragments.

FIGURE 10.—*Photomicrograph of Graphite-bearing Quartzite. Ordinary Light.* (× 20)

Locality, three-fourths mile southwest of Vera Cruz, Allentown quadrangle. Specimen 7788. The pale mineral is quartz, the dark graphite; carbonaceous dust spreads out from some of the graphite plates into the quartz, appearing to cause a bluish color in the latter.

FIGURE 11.—*Photomicrograph of basic Gneiss. Ordinary Light.* (× 20)

Locality, 1½ miles southwest of Lower Saucon, Allentown quadrangle. Specimen 6876. The dark mineral is hornblende, the white oligoclase feldspar, the gray band crossing horizontally below the center sericite with dark patches of augite; there is no indication that the hornblende is an alteration product of the augite, and both are thought to have formed simultaneously in the course of feldspathization of a shale.

FIGURE 12.—*Photomicrograph of basic Gneiss showing rounded Zircons. Ordinary Light.* (× 100)

Locality, 3 miles northwest of Boyertown. The clear mineral is orthoclase feldspar, and several zircons are visible, standing out in relief, near the center of the field; they are well rounded and of different sizes.

position. The phenomena of feldspathization are in every respect like those described in connection with the quartz-mica schist above. When graphite is present in the granitic bands it is, as a rule, coarser than in the quartzitic ones, showing that recrystallization of this mineral has taken place (as with sillimanite in the other rock). Indeed, when the magma has been pegmatitic the graphite plates are at times 3 to 5 centimeters across, whereas in the original rock they are measured in as many millimeters.

TABLE 6.—*Mineral Composition of feldspathized Graphite-bearing Quartzite*

	1	2	3	4
Quartz	48.9	43.4	34.9	40
Feldspars	....	....	....	45
Orthoclase	18.7	26.8	35.4	...
Oligoclase	14.6	17.7	20.5	...
Graphite	14.9	3.4	4.6	10
Accessories	....	....	....	5
Biotite	....	5.5	4.3	...
Garnet	0.1	1.4	0.2	...
Zircon	0.05	0.05	0.05	...
Pyrite and limonite	2.7	1.75	....	...
Apatite	0.05	....	0.05	...
Totals	100.00	100.00	100.00	100

The localities of the above are all on the Allentown quadrangle, as follows:

1. One-fourth mile southwest of Shimer station (which is wrongly located on the topographic map) (5217).
2. One-fourth mile east of Limeport (7947).
3. One mile southwest of Lower Saucon (6854).
4. The rounded-off average of 1, 2, and 3.

BASIC (AMPHIBOLITE) GNEISS

CHARACTER

The nature of the original materials from which the basic gneisses[13] of this region have been derived can only be conjectured, since none but rocks resulting from profound magmatic modification are now known. These feldspathized phases are characterized by the abundance of quartz, hornblende (or biotite or augite), and of both orthoclase and oligoclase feldspars; a typical section is shown in figure 11. Ilmenite or magnetite is a prominent accessory, and rounded zircons can sometimes be found,

[13] In Canada and the Adirondack region rocks like these are called amphibolite. The origin here assigned corresponds to one of those described in Adams and Barlow's much quoted paper: Can. Dept. Mines, Geol. Survey, Memoir 6, 1910, p. 87, etcetera.

as seen in figure 12. Counts of the areas occupied by these minerals in several thin sections are given in tables 7 and 8.

TABLE 7.—*Mineral Compositions of typical basic Gneisses*

	1	2	3	4
Quartz	13.8	17.8	27.8	25
Feldspars:				
Oligoclase	48.5	49.0	52.9	45
Andesine	2.5	....	2.8	3
Orthoclase	1.0	1.3	0.6	1
Hornblende	24.6	27.8	3.8	20
Augite	8.0	4.0	11.0	5
Accessories	....	....	....	1
Ilmenite	1.55	0.05	1.05	...
Zircon	0.05	0.05	0.05	...
Totals	100.00	100.00	100.00	100

The localities represented are as follows, all being on the Allentown quadrangle:

1. One mile northeast of Limeport (7916).
2. West end of Seidersville (5873).
3. One mile southeast of Mountainville (290).
4. The rounded-off average of 1, 2, and 3.

TABLE 8.—*Mineral Compositions of unusual basic Gneisses*

	1	2	3
Quartz	5.0	.....	2.0
Feldspars:			
Orthoclase	2.6	5.2	.....
Microperthite	51.4	.....	.....
Oligoclase	1.2	54.0	.....
Andesine	....	.....	65.2
Hornblende	....	14.8	.....
Augite	39.5	.....	.....
Hypersthene	....	25.6	17.8
Biotite	....	.....	14.8
Accessories:			
Ilmenite	0.1	0.4	0.2
Titanite	0.2	.....	.....
Totals	100.0	100.0	100.0

These are from:

1. One mile southeastof South Bethlehem (5869).
2. Near Seidersville (335).
3. One mile east of Freemansburg (6458).

ORIGIN

As noted above, under the heading "Crystalline limestone," amphibolitic and pyroxenitic gneisses have locally been developed by metamorphism of that rock, but there is no evidence that any considerable proportion of the basic gneisses of this region have been thus formed. The primary rock in the majority of cases was more probably shale. The most important point to be decided, however, is not what sort of sediment they may have arisen from, but whether they are of sedimentary origin at all; for the gneisses produced by the recrystallization of igneous rocks, such as gabbro, may be similar in some respects. In the Piedmont belt of Precambrian rocks the basic gneisses are regarded as almost exclusively metamorphosed gabbro.[14] But the relations in the northern belt are believed by the writer to indicate the ultimate sedimentary origin of the bulk of these rocks. In addition to the reasons for the conclusion that much of the corresponding Pochuck gneiss is a metamorphosed sediment, given in the New Jersey folios above cited, the following points are worthy of note:

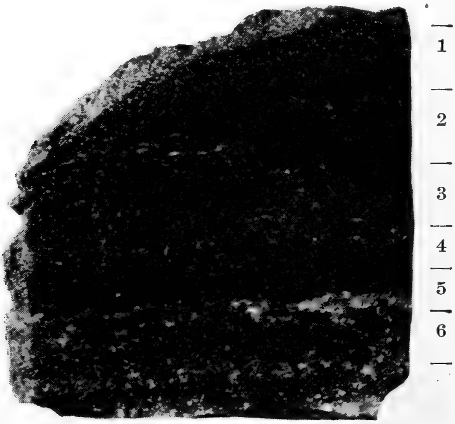

Figure 13.—***Basic Gneiss showing Alternation of dark and light Bands.*** **(× ½)**

Locality, same as figure 12. The right-hand side of this specimen was sawed off and thin sections made all the way across; counts of the minerals in these are given in table 9, the numbers marked on the figure corresponding to those in the table; No. 5 is a sill of granite.

The mineralogical evidence in favor of a sedimentary origin of these rocks is not as complete as in the case of the formations previously described, since only feldspathized phases are known. The rounded zircons which can be found in these basic gneisses are, however, as pointed out above, an excellent evidence of sedimentary origin. The presence of augite is not regarded as opposing such an origin, for augite frequently forms during the metamorphism of sediments, especially if they are somewhat calcareous.

The original minerals having been extensively, if not completely, recrystallized and rearranged, it is unsafe to base any conclusions on the present mineralogical features of the rock as a whole. But the structural relations shown in many instances are similar to those of the previously

[14] F. Bascom and others: Philadelphia Folio, U. S. Geol. Survey, No. 162.

described formations. For instance, rapid alternation in composition across the bands, but persistence of individual bands for considerable distances along the strike, are more suggestive of sedimentary than of igneous origin. To bring out the manner in which alternation occurs, a specimen 8 centimeters across—shown in figure 13—in which six bands could be recognized, was sawed through and thin sections of its entire cross-section prepared; counts of areas occupied by the several minerals are recorded in table 9.

TABLE 9.—*Mineral Composition of a banded basic Gneiss*

	1	2	3	4	5	6
Width of band, centimeters.	2.0	1.7	1.4	1.1	0.5	1.3
Color	gray	black	gray	black	white	black
Quartz	11.4	11.0	20.4	20.6	19.7	3.6
Feldspars:						
Orthoclase	54.2	32.3	57.8	35.6	....	49.7
Oligoclase	7.2	2.4	5.2	7.0	....	5.6
Microperthite	....	....	....	....	80.2	....
Augite	15.2	....	8.5	....	....	....
Hornblende	6.6	50.0	3.0	32.7	....	36.8
Accessories:						
Magnetite	5.35	4.25	5.05	4.05	0.05	4.25
Zircon	0.05	0.05	0.05	0.05	0.05	0.05
Totals	100.00	100.00	100.00	100.00	100.00	100.00

Locality—Three miles northwest of Boyertown.

Band 5 is shown by its macroscopic aspect and its mineral content to be a tiny sill of granite, but the other bands show no evidence of igneous origin, except in so far as feldspathization has been produced in them by emanations from magmas.

The relations to the other rocks of the region are equally significant. The basic gneisses are almost always intimately associated with the other sedimentary formations here described. They are in particular frequently interbedded with the graphite-bearing quartzite, and they may always be found to a greater or less extent adjacent to the limestones and to the quartz-mica schist.

When the basic gneisses occur in the vicinity of the granites, many features indicate the subsequent age of the latter. In this respect the relations described by Doctor Fenner in the paper above cited are duplicated repeatedly in the present region. Basic laminæ often come to an end against typical granite, and angular inclusions of basic rocks are frequent in the latter. Evidence that the granite magma has softened the basic rock is found in the pinching and swelling of some layers while

adjacent ones remain straight, and in other similar ways. It is thereby rendered certain that the basic bands can in no way represent dikes of gabbro or anything of that sort penetrating the granite; they must have been solid and laminated before the granite came in. This fact alone, as Doctor Fenner cautiously points out, is not a proof of the sedimentary origin of the basic bands, for they might be igneous rocks which had been laminated by metamorphism prior to the granitic intrusion; taken in connection with the evidence favoring a sedimentary origin derived from other relations, however, it has strong confirmatory value.

From these basic gneisses, in which the dark minerals are so large in amount as to render the whole rock dark in color, there exist all gradations to acidic igneous rocks which are mainly light in color, but show lines and streaks of dark minerals; a specimen of one of these is shown in figure 14. To what extent the latter represent primary alignment of the tabular minerals, on the one hand, and remnants of preexisting laminated rocks which have been melted up in the magmas without losing their structure entirely, on the other, it is impossible to decide from the limited exposures in this region. The association with basic gneisses which these occurrences show indicates, however, that the second relation holds in many cases. The original extent of sedimentary Precambrian formations in this region was therefore, no doubt, even greater than that described in this paper.

FIGURE 14.—*Granite showing Streaks of dark Minerals.* (× ½)

Locality, near South Bethlehem, Allentown quadrangle. Specimen 222. The dark bands are believed to represent laminæ of basic gneiss, which has been melted up and largely assimilated by the granite.

SUMMARY

In the foregoing pages descriptions have been presented of several types of rocks occurring in the northern belt of Precambrian in Pennsylvania which give evidence of ultimate sedimentary origin. The evidence is partly mineralogical, partly structural, and partly derived from relations to rocks of igneous origin. These sediments have been extensively feldspathized and more or less completely assimilated by the magmas, but enough of them is preserved to indicate the existence in this region of a considerable body of Precambrian sedimentary formations.

GALENA LIMESTONE QUARRY, NEENAH, WISCONSIN

View looking southwest. 1. Red till. 2. Yellow gravel (Wisconsin drift). 3. Fluorite zone. 4. Massive crystallized Ordovician limestone. 5. Thin-bedded blue shale at base of quarry.

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FLUORSPAR IN THE ORDOVICIAN LIMESTONE OF WISCONSIN[1]

BY RUFUS MATHER BAGG

(Read before the Society December 29, 1917)

CONTENTS

INTRODUCTION

Fluorite was discovered last summer by the writer while examining the galena limestone quarries at Neenah, Wisconsin, when on a field excursion with the geological students of Lawrence College. Since this mineral has never been mentioned as occurring in the Ordovician of this State, and also because its apparent absence has been the repeated cause for especial mention in various State geological reports, it seems worth while to call attention to this discovery.

REFERENCES BY OTHER OBSERVERS

Prof. J. D. Whitney,[2] in discussing the minerals of the "lead region" in 1862, gives the following description of fluor:

> "The element fluorine seems to be very scantily and irregularly distributed through the Paleozoic rocks of the Northwest. Even where these have been partially metamorphosed by igneous agencies, as on Lake Superior, fluorspar is of very infrequent occurrence; indeed, we are not aware of its having been discovered in more than two or three localities."

[1] Manuscript received by the Secretary of the Society December 28, 1917.
[2] Geology of Wisconsin, vol. i, 1862. Mineralogy, by J. D. Whitney, p. 205.

He then states what is more significant with reference to our discovery:

> "No traces of this mineral have been observed in any of the unaltered rocks of Silurian age farther west than New York, so far as can be ascertained." "The lead region of Wisconsin, Iowa, and Illinois has failed to furnish a single specimen." "Nor has a trace of fluor been observed in the great expanse of territory covered by the Niagara limestone in Illinois and Iowa."

Twenty years later, when R. D. Irving[3] published his check list of minerals found in Wisconsin, fluorite is mentioned as occurring in minute purplish particles in the pink granite of Ashland County; but he further adds: "The complete absence of fluorite—which is so common an associate of lead ores—from the lead ores of Wisconsin is worthy of note."

Since both galena and fluorite are present in small amounts in the strata of the Neenah quarries, even though not abundant enough to become of commercial value, the above statements no longer hold true, for these dolomitic limestones are of the same horizon as those of the lead region.

Location of the Quarries and glacial Deposits therein

The quarries described in this paper are situated in the southeast edge of Neenah, below the city park and about 1,000 feet west of Lake Winnebago. The upper surface of the limestone shows strong glacial planation cut by striæ trending north 25° east (magnetic), with some weaker striations crossing these, while on the southeast margin of the smaller quarry some small cuplike depressions occur. The southwest border of the larger quarry is covered by 7 feet of glacial drift, which is sharply divided into two deposits. The lower formation is 4 feet thick and rapidly thins out northward. It is overlain here by 3 feet of glacial till, resembling the red clay so extensively developed along the Fox River valley. There are some rather large striated and faceted gabbro and granite boulders scattered sparingly through this upper deposit, but beneath this is a yellow gravel composed of small fragments of angular limestone with but few of the larger igneous glaciated boulders present.

The accompanying vertical section shows the relation of these glacial deposits to the underlying Ordovician limestone.

Mode of Occurrence of the Minerals

The fluorite occurs in a definite layer of massive limestone about 5 feet from the bottom of the main quarry. It consists of bright purple coat-

[3] Geology of Wisconsin, vol. i, 1882. Minerals of Wisconsin, pp. 309, 314.

ings in seams and joint planes and encrusts some vein fillings beneath it. The first vein crystallization is usually calcite in thin, almost transparent,

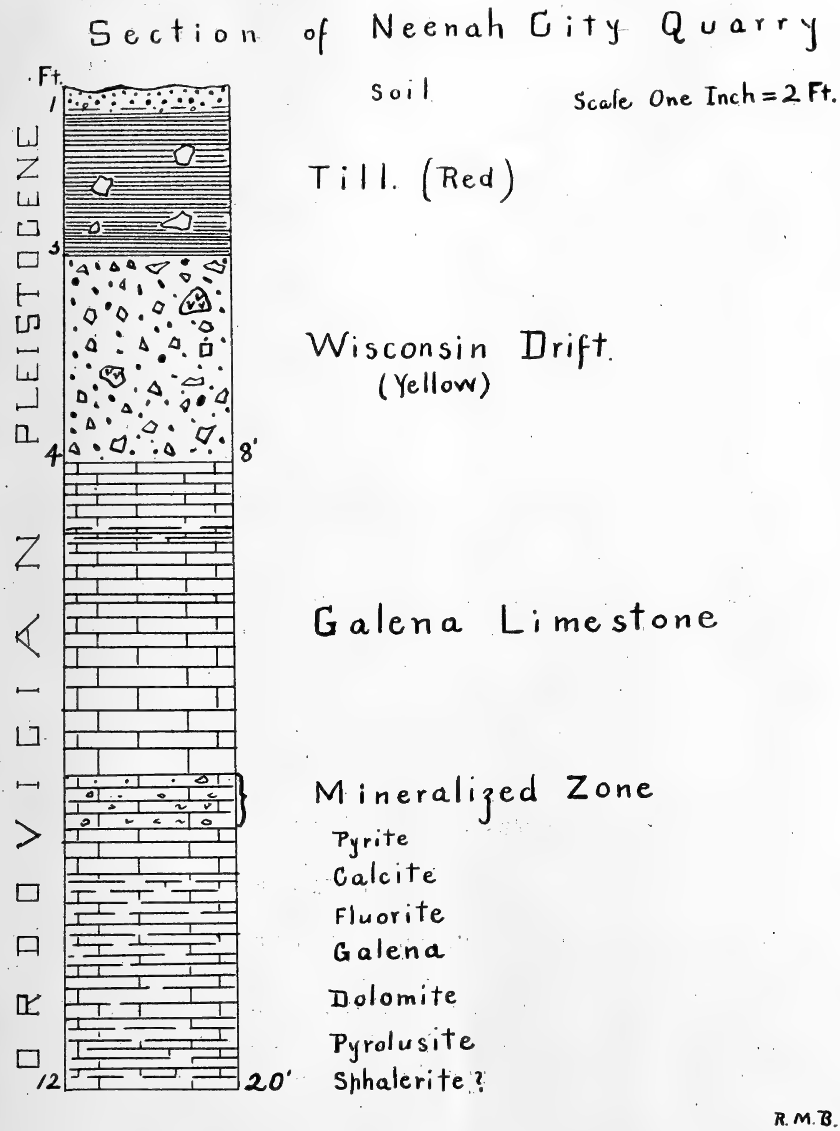

FIGURE 1.—*Section of Limestone Quarry at Neenah, Wisconsin*

rhombs, but often with scalenohedron combinations in the more open vugs. The calcite was followed by a layer of iron pyrites, which as tiny

cubes and pyritohedrons cover the calcite surface. In some cases these pyrite crystals formed before the calcite was completely solidified, as shown by intergrowths, but as a rule the two layers are quite distinct.

The third coating of vein matter filling the joint-planes and seams is fluorite, but in some places this seems to cover the blue limestone surface without the two minerals above referred to underneath. Since the pyrite is highly tarnished and iridescent, it shows in places through the fluorspar.

Galena occurs in this same zone and appears as a thin coating on the joint surfaces, with here and there a large well defined cube in the solid crystalline dolomite.

While the fluorite usually coats the calcite and pyrite, it is also found on some of the galena seams and more rarely on the limestone walls, but in every case it is the last mineral which was deposited. This Neenah fluorite does not develop, however, into good crystals, at least so far as observed, but the coating is heavy, the color intensely purple, and there is sufficient present to give a good etching test. The minerals above referred to appear to be confined to the south side of the larger quarry, where they develop in a massive blue limestone 1 foot thick and some 5 feet above the bottom workings.

Underneath the upper massive dolomite strata the beds become shaly and are very rich in bryozoa, brachiopod, and algæ remains. When quarried these dark blue shales are so soft that they can be broken in the hands and the rock is discarded in crushing.

The calcite occasionally assumes a beautiful and delicate rose color, and in one geode center of an orthoceras cast the pink lies in a zonal band surrounded by transparent spar, while the outside of the cast showed galena over the argillaceous surface and stained with purple fluorite.

Origin of the Fluorite

It is unlikely that the fluorite under discussion could have been derived from igneous rock which lies deeply buried in the Neenah region. Granite is 675 feet below this same formation 16 miles to the southwest at Oshkosh, and as these quarries lie directly along the strike this same granite can not be far from 700 feet deep under Neenah.

These limestones dip slightly eastward, and from well borings at Appleton and at Hortonville we have determined this regional dip to be 17 feet to the mile. At the Neenah quarries there is a small dome-shaped curvature and the dip is not uniform, but this may not be structural if the strata were laid down on an undulating base.

At Kaukauna, a few miles farther north, similar Ordovician strata show small fault-planes, and these are filled with calcite and pyrite, as at Neenah. No such faulting was observed at Neenah, however, and the vein fillings are not as pronounced as at Kaukauna.

If the fluorite came from below, we should find it at Kaukauna, where faulting occurs in the same limestone, and it should be distributed in more than one stratum.

Large and pronounced rhombic jointing at Neenah cut all the upper layers on massive dolomite, but these joints do not extend downward into the bryozoa shales at the base, at least not where at present exposed.

It seems more probable, therefore, to the writer that this fluorite was syngenetically deposited in very minute quantity with the galena dissemination from mineralized Ordovician waters, and that later this was precipitated as a thin coating along more open joint-planes and solution chambers in more crystalline dolomite.

The presence of fluorine is definitely known in existing oceanic waters, and in Ordovician oceans may have been locally present in larger amount, and thus could have been contemporaneously deposited in the dolomite along with galena, iron sulphide, and calcite, whose secondary enrichments now fill these openings.

Since the jointing is very limited vertically and because we find no evidence of faulting at Neenah, we believe the fluorite was precipitated from lateral secretion. It is not impossible, however, that meteoric waters percolating downward in strata now eroded have added some mineral matter in this layer above the more impervious shales. We do not believe that it came from any deep-seated action, as was so often the case in the igneous rocks of the West.

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ADIRONDACK ANORTHOSITE *

BY WILLIAM J. MILLER

(Presented in abstract before the Society December 29, 1917)

CONTENTS

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Manuscript received by the Secretary of the Society January 14, 1918.

Introduction

This paper takes up the whole problem of the structure, relations, and origin of the great body of anorthosite in the Adirondack region. References are made to anorthosites of other well known regions, and it is hoped that some important light may be thrown on the problem of the anorthosites in general. Particular attention is given to Bowen's recent paper,[1] "The problem of the anorthosites," in which he elaborates an hypothesis regarding the structure and origin of anorthosite with special reference to that of the Adirondacks. I regard this paper as a very important contribution to the subject, because he has called attention to many important features hitherto either overlooked or not sufficiently emphasized. But, as a result of more than six months of field-work within and close to the Adirondack anorthosite area and much laboratory work, I find Bowen's hypothesis untenable.

Still more recently, by way of discussion of Bowen's paper, two short articles by Cushing[2] and one by Bowen[3] have appeared. I also consider the main points of these papers.

In the perusal of the papers just referred to, one is repeatedly struck with the meagerness of evidence based on actual field facts. Up to the time of the appearance of Bowen's paper, "The problem of the anortho-

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[1] N. L. Bowen: Jour. Geol., vol. 25, 1917, pp. 209-243.
[2] H. P. Cushing: Jour. Geol., vol. 25, 1917, pp. 501-509 and 512-514.
[3] N. L. Bowen: Jour. Geol., vol. 25, 1917, pp. 509-512.

sites," comparatively little data regarding the structure and origin of the Adirondack anorthosite had been published, and all such material was gathered without Bowen's hypothesis in mind. Thus many of the important facts bearing on the problem were either only slightly considered or not thought of at all. The only detailed geologic maps representing portions of the anorthosite area were the following New York State Museum quadrangle maps: Long Lake, by professor Cushing; the Elizabethtown-Port Henry, by Professor Kemp, and the Paradox Lake, by Doctor Ogilvie. Of these only the first two are accompanied by reasonably full descriptions of the anorthosite, and these two maps show more or less separate representations of the border facies of the anorthosite.

It is evident, then, that published data pertaining to the Adirondack anorthosite, and particularly facts bearing on Bowen's hypothesis, are meager.

None of the results of my many months of field and laboratory studies pertaining to the anorthosite area, more especially those portions comprised within the Lake Placid and Schroon Lake quadrangles, but also somewhat in other quadrangles, have yet been published. My last summer's work was done with Bowen's paper in hand. Among the many observations which I have made, some strongly support Cushing's contention that the anorthosite is a separate intrusive body distinctly older than the syenite-granite series. Many of my observations, however, have new bearings and these throw important light on the anorthosite problem. The purpose of this paper is, then, to present and to show the significance of all the more important evidence, both old and new, which bears on the structure and origin of the Adirondack anorthosite.

Adirondack Rocks in General [4]

The Grenville series comprises the oldest rocks of the Adirondack region, and they are generally considered to be of Archeozoic age. They consist of a great mass of strata thoroughly crystallized into various gneisses and schists, calcite marble, and quartzite. A more or less well developed foliation is always parallel to the stratification surfaces, which are usually distinctly preserved in spite of the complete crystallization. Grenville strata are well represented throughout most of the Adirondack region, their distribution being very irregular or "patchy," because they have been so badly cut to pieces by great bodies of intrusive rocks. Because of the breaking up of the Grenville into masses great and small by

[4] Detailed accounts of the rocks may be found in the various New York State Museum Bulletins pertaining to the region.

the intrusives, the strata are often highly tilted or moderately bent, and in some places locally contorted; but there is no evidence that these rocks have ever been severely folded by orogenic forces. The thickness of the Grenville is certainly at least a few miles. Adams and Barlow report a thickness of about 18 miles in Ontario.

My view is that the oldest known intrusive is now represented by the anorthosite, which worked its way upward as a relatively stiff gabbroid magma, probably laccolithic. This rising magma, for most part, lifted or domed the Grenville strata over it, but also, to some extent, engulfed fragments of the Grenville. The anorthosite proper is thought to have differentiated from the gabbroid magma, as explained beyond in this paper.

Distinctly later, though apparently not much later, came the intrusion of a tremendous body of magma now represented by syenite-granite series, so common throughout most of the Adirondack region. This vast magma, for most part, slowly and very irregularly worked its way upward, in places actually doming the Grenville, but mostly either breaking up or tilting masses of it, great and small, or breaking through it as great offshoots from the magma, or more intimately intruding or even injecting it.

Cushing[5] holds "that a complex of Grenville, resting on orthogneiss, existed in the region at the time of the intrusion of the anorthosite-gabbro group; that much of this orthogneiss still remains in the region, and that the later intrusive broke through this complex in separate masses instead of forming one great body." Possibly such an older orthogneiss is present, but I maintain that no real proof for its existence has been thus far presented, and that if it does exist it must be in minor amount. After many seasons of detailed field-work in the Adirondack area, I have found no positive evidence for the existence of such an older orthogneiss in the areas mapped either by others or by myself.[6] In my opinion, the presence or absence of such an older orthogneiss has no important bearing on the problem of the anorthosite, though, as pointed out beyond, if we consider it to be absent we arrive at a somewhat more rational explanation of the origin of the anorthosite. I have never maintained, as Cushing seems to imply, that the anorthosite and the syenite-granite series are differentiates of a single great intrusive body. With Cushing, I have always believed the anorthosite to be a distinctly earlier intrusive, but I do not believe it has ever been proved that what we regard as the great syenite-granite series was intruded as distinctly separate masses, as Cushing implies. Here, again, I am open to conviction; but in all my experience I have

[5] H. P. Cushing: Jour. Geol., vol. 25, 1917, p. 504.

[6] The Thousand Islands district, really beyond the Adirondack Mountain area proper, is not considered in this paper.

found only occasional small dikelike masses of granite or aplite and numerous pegmatite dikes cutting the great syenite-granite series. After all, my view of the intrusion of the syenite-granite series may not be very different from that of Cushing, because I consider the tremendous body of magma to have worked its way upward, slowly and irregularly, sending out many offshoots which may have come to rest and congealed at slightly different times.

Still later than the syenite-granite series are the gabbro stocks and dikes. In my experience these are mostly stocks, never more than a few miles across, with elliptical ground-plan and practically vertical walls. They usually exhibit finer grained amphibolitic border facies, while the interior portions are usually medium to coarse grained with distinct ophitic texture and more or less gneissoid. Such gabbro masses are common throughout the Adirondacks, except well within the anorthosite area. The notable absence of Grenville strata, syenite-granite series, and gabbro stocks from well within the area of the typical anorthosite all have important bearings on the problem of the origin and structure of the Adirondack anorthosite.

Latest of all the intrusives is diabase in the form of small typical dikes with nearly vertical walls. They are very common throughout the Adirondacks, showing no marked tendency to be absent from the anorthosite area.

General Description of the Anorthosite

EXTENT OF THE ANORTHOSITE AREA

As far as definitely known, the anorthosite was the first of the great intrusive bodies to break into the Grenville strata. As shown beyond in this paper, the anorthosite is demonstrably older than the syenite-granite series and intruded by the latter. With the exception of a few small outlying masses, this rock occupies a largely unbroken area of about 1,200 square miles of the central-eastern Adirondack region.

MARCY TYPE OF THE ANORTHOSITE

By far the most abundant facies of the rock I shall call Marcy anorthosite because of its great exposures on Mount Marcy. The most typical portion of the Marcy anorthosite is very coarse grained, light to dark bluish gray, and consists very largely of basic plagioclase feldspar, mainly labradorite. The dark bluish gray labradorite crystals usually vary in length from a fraction of an inch to several inches, crystals about an inch long being very common. Only occasionally do these labradorites exhibit

the play of colors generally so characteristic of this species of feldspar. Twinning striations are often evident on the cleavage faces.

Accessory minerals visible to the naked eye are large individuals of pyroxene and hornblende and small individuals of biotite, ilmenite, pyrite, garnet, and more rarely chalcopyrite or pyrrhotite. These accessory minerals ordinarily constitute 5 to 10 per cent of the typical coarse anorthosite, but there are local developments of the rock which are made up almost entirely of plagioclase, and still others, rather abundantly developed, which contain from 10 to 25 per cent of dark minerals, these last named types really being anorthosite-gabbros.

An important facies of the anorthosite is one in which the dark labradorite individuals, from a few millimeters to an inch or more across, stand out conspicuously in a distinctly granulated ground-mass of feldspar. The granulated material varies from light gray to pale greenish gray. It is very evident that the large labradorites are roughly rounded uncrushed cores of what were considerably larger individuals before the rock was subjected to the process of granulation. All degrees of granulation are exhibited to extreme cases where the rock has been so thoroughly granulated that few, if any, labradorite cores remain.

Much of the typical Marcy anorthosite is practically devoid of foliation, though in some local zones of almost perfectly pure plagioclase rock there is a notable tendency for the feldspars to show a crude parallelism. The more gabbroid facies of the rock, however, often exhibit a fair to well defined foliation accentuated by the parallel arrangement of the femic minerals.

In thin section, with a low power of the microscope, the larger labradorites are usually seen to be more or less filled with myriads of very dark dustlike particles, probably ilmenite.

CHILLED BORDER FACIES OF THE ANORTHOSITE (WHITEFACE ANORTHOSITE)

Around the borders of the great body of anorthosite, and in some places a number of miles within it, there is quite generally a notable increase in femic minerals, causing the rocks to be anorthosite-gabbro or even gabbro. Such rocks are almost invariably medium grained and therefore notably finer grained than the typical Marcy anorthosite, though in some localities a few large, scattering labradorite individuals occur. A foliated structure is generally well developed.

Although they are more or less variable in general appearance and composition, I here propose that these border phases of the anorthosite be classed as Whiteface anorthosite, a name given by Professor Kemp to a

type of the anorthosite which occurs abundantly on Mount Whiteface, near Lake Placid. At the summit of Mount Whiteface the rock is medium grained and consists of white plagioclase (chiefly labradorite) with 10 to 15 per cent of dark minerals scattered through the mass parallel to a crude foliated structure. This rock stands out in marked contrast against the typical Marcy anorthosite, which is not so gabbroid, very coarse grained, light to dark bluish gray, and generally not well foliated. More exceptionally the Whiteface type is nearly pure white, being quite free from femic minerals. Much of the rock, however, is locally richer in dark minerals, which may constitute 15 to 30 per cent of the whole. The minerals other than the feldspar are practically the same as in the Marcy anorthosite.

Whiteface anorthosite is unusually extensively developed within the Lake Placid quadrangle. It there has a very irregular distribution, but in a broad way it is quite certainly to be regarded as a border phase of the Marcy anorthosite.

My very recent survey of the Schroon Lake quadrangle shows that the Whiteface rock there exists as a distinct border facies of the Marcy anorthosite, though it has been notably cut to pieces and more or less assimilated by the syenite-granite series, as explained beyond.

I have also noted Whiteface anorthosite as a border facies in the Newcomb quadrangle and in portions of the Ausable quadrangle.

Kemp describes a considerable development of Whiteface anorthosite as a border or rim facies of the more typical anorthosite in the Elizabethtown and Port Henry quadrangles. He maps it with "basic anorthosite and related types," so that its actual extent is not shown.

Cushing has described a commonly occurring gabbroid border facies of the western border of the anorthosite, particularly in the Long Lake quadrangle. Regarding the latter he says:

> "This border gabbro is a rather uniform grained rock, of sufficient coarseness, so that the white of the feldspar, the red of the garnet, and the black of the pyroxene, hornblende, and magnetite are all prominent. In the less extreme phases of the rock occasional small uncrushed cores remain." [7]

Judging by Cushing's description elsewhere,[8] this western border facies of the anorthosite differs from the typical Marcy anorthosite in being usually less gneissoid and generally not so characterized by white feldspar.

Enough detailed work has therefore been done to make it evident that the great body of Adirondack anorthosite has a pretty well defined border

[7] H. P. Cushing: N. Y. State Mus. Bull. 115, 1907, p. 474.
[8] H. P. Cushing: N. Y. State Mus. Bull. 95, 1905, pp. 310-311.

facies which is distinctly more gabbroid, more gneissoid, and finer grained than the typical Marcy anorthosite, and which usually is characterized by light gray or white instead of dark bluish gray feldspar. Further, both the border (Whiteface) and Marcy types of the anorthosite are quite certainly differentiation phases of the same cooling magma, the former no doubt representing a chilled border portion. The one type grades into the other and nowhere has one been found to definitely intrude the other.

CHEMICAL COMPOSITION

Analyses of both the Marcy and Whiteface types of anorthosite have been made for and described by Professor Kemp. They are as follows:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O+	CO_2	TiO_2	S	P_2O_5	MnO
1..	54.47	26.45	1.30	.67	.69	10.80	4.37	.92	.53	..	..	..	..	..
2..	53.18	23.25	1.53	1.82	2.60	11.18	3.97	.86	1.13	.34	.45	tr.	.09	.11

Number 1 represents an analysis by A. R. Leeds of the rock from the summit of Mount Marcy. In the quantitative classification it belongs in Class 1 (Persalane), order 5 (Canadare), rang 4 (Labradorase), subrang 3 (Labradorose). Number 2 represents an analysis by George Steiger of the rock from the summit of Mount Whiteface. In the quantitative classification it falls in Class 2 (Dosalane), order 5 (Germanare), rang 4 (Hessase), subrang 3 (Hessose). These two analyses are doubtless very representative of the more common Marcy and Whiteface types of anorthosite. They show close similarity in chemical composition. Order, rang, and subrang are the same for both, the difference in class no doubt being due to the somewhat greater percentage of femic minerals in the Whiteface rock.

The rather high percentage of potash in rocks of this character calls for explanation. Lack of such dark minerals as would furnish enough potash causes Kemp[9] to think that orthoclase must be present up to 5 per cent or more as untwinned feldspar. Cushing,[10] however, says: "The potash is in the labradorite (or other plagioclase), replacing a certain amount of soda," and "that analyses of this feldspar always show it." If potash feldspar is present I have been unable to demonstrate it in the thin sections which I have examined.

Bowen's Hypothesis regarding Origin of Anorthosite

Since Bowen has elaborated an hypothesis to account for the structure and origin of anorthosites in general, but with considerable attention to

[9] J. F. Kemp: N. Y. State Mus. Bull. 138, 1910, p. 80.
[10] H. P. Cushing: N. Y. State Mus. Bull. 95, 1905, p. 335.

the Adirondack anorthosite, it is important for the reader to have this hypothesis clearly in mind. In order to fairly and succinctly state this hypothesis, I take the liberty of quoting a considerable portion of the summary of Bowen's first paper,[11] as follows:

"Anorthosites are made up almost exclusively of the single mineral plagioclase, and in virtue of this fact they present a very special problem in petrogenesis. The conception of the mutual solution of minerals in the magma and the lowering of melting temperature consequent thereon is no longer applicable. Yet anorthosites give no evidence of being abnormal in the matter of temperature to which they have been raised; in other words, they give no evidence of having been raised to the temperature requisite to melt plagioclase. A possible alternative is that they may never have been molten as such, and are formed simply by the collection of crystals from a complex melt, probably gabbroic magma. . . .

"A consideration of the method whereby the accumulation of plagioclase crystals might take place leads to the conclusion that the most promising is the separation by gravity of the femic constituents from gabbroid magma, while the plagioclase crystals, which are basic bytownite, remain practically suspended. Then, at a later stage, when the liquid has become distinctly lighter, having attained diorite-syenite composition, the plagioclase crystals, which are now labradorite, accumulate by sinking and give masses of anorthosite, at the same time leaving the liquid out of which they settle of a syenitic or granitic composition.

"Some of the consequences of this manner of origin of anorthosite are as follows: Typical anorthosite, very poor in bisilicates, should not occur as small dikes, for a mass of accumulated crystals should have little invading power. . . . Typical anorthosite should for like reasons not occur as an effusive rock. . . . Anorthosite should be intimately associated with gabbro, but perhaps as intimately with syenite or granite. Anorthosites should commonly be labradorite rocks rather than bytownite or anorthite rocks.

"For the Adirondack area especially, evidence is adduced favoring the possibility that there anorthosite and syenite may still occupy the relative positions in which they were generated by the process outlined, the Adirondack complex being interpreted as a sheetlike (laccolithic) mass with syenite above and anorthosite below."

In his second paper[12] Bowen modifies this hypothesis and interprets the whole Adirondack igneous complex as a tremendous laccolith, with essentially a stratiform arrangement of pyroxenite and gabbro below; next above, anorthosite, and an upper chilled gabbroid border, the consideration of a chilled border having been a result of Cushing's rejoinder to Bowen's first paper.

In the development of his hypothesis, Bowen also stresses the following: (1) Common occurrence of rocks intermediate between syenite and

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[11] N. L. Bowen: Jour. Geol., vol. 25, 1917, pp. 242-243.
[12] N. L. Bowen: Jour. Geol., vol. 25, 1917, pp. 512-514.

anorthosite; (2) meager evidence of syenite intrusions in anorthosite, and (3) common occurrence of intimately mixed Grenville and syenite, but absence of intimately associated Grenville and anorthosite.

Significance of the variable Composition and Structure of the Anorthosite

According to Bowen, "anorthosites are made up almost exclusively of the single mineral plagioclase," and therefore "the conception of the mutual solution of minerals in the magma and the lowering of temperatures consequent thereon is no longer applicable."

My experience in the field, with this idea of the composition of the Adirondack anorthosite definitely in mind, has convinced me that the rock is by no means an almost perfectly homogeneous mass of plagioclase. The main bulk of the Marcy anorthosite contains 5 to 10 per cent of minerals other than plagioclase. Portions with about 10 per cent are common, and in many places there are 10 to 20 per cent, or even more, of dark minerals. It is also true that some portions of the mass contain less than 5 per cent of dark minerals visible to the naked eye. Conservatively estimated, I believe the average Marcy anorthosite carries fully 10 per cent of minerals other than plagioclase.

In my field-notes on both the Lake Placid and Schroon Lake quadrangles, I have recorded many observations of anorthosite-gabbro and more typical anorthosite exhibiting perfect gradations from one into the other. Such gabbroid facies exist locally throughout the anorthosite body, in many places as rather distinct zones or belts a few feet or rods wide, and in other places on much larger scales. Many other gabbroid portions are much more irregular in shape and not so distinctly separated from the purer anorthosite.

Similar irregularities in the Morin anorthosite near Montreal have been described by Adams,[13] who says:

> "This irregularity is sometimes scarcely noticeable, but is at other times striking, and is due to concentration of the bisilicates and iron ore in some parts of the rock. The portions richer in bisilicates may take the form of large irregular shaped patches occurring at intervals through the rock, or of many small patches occurring abundantly in certain parts of the rock which elsewhere is nearly free from them. In some cases these are arranged to form irregular wavy streaks instead of patches. Sometimes these patches are rudely parallel, giving a sort of strike to the rock, but in other places they are quite irregular in arrangement. Between these patches or streaks rich in bisilicates, and rather badly defined against them, are portions of the rock which are very poor in or often quite free from bisilicates."

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[13] F. D. Adams: Geol. Sur. Can., Guide Book No. 3, 1913, p. 10.

This description applies almost equally well to the Adirondack anorthosite. Most of such gabbroid facies are quite certainly due to local differentiation essentially *in situ,* with more or less shifting of the differentiates during a late stage of magma consolidation.

Lawson,[14] in his study of the Minnesota anorthosite, recognizes a small content of femic minerals in the anorthosite in general, and also some dark bands, a few inches to a few feet wide, rich in augite and not sharply separated from the adjacent normal anorthosite. One of these bands dips from 60 to 70 degrees. At one locality he observed a sort of stratiform structure "due to the fact that there are certain sheetlike layers somewhat richer in pyroxene than the rest of the rock," and he explains this as "essentially due to some local chemical differentiation associated with movement in the thickly viscous magma prior to crystallization."

N. H. Winchell[15] found the Minnesota anorthosite to be much less pure plagioclase and less constant in composition than Lawson, and he states: "Thin sections have revealed in the feldspar boulders, however pure they may be to the eye, small quantities of augite, and from these minute quantities there are all gradations to typically constituted gabbro." This conclusion is confirmed by Elftman as a result of extended field studies.

Coleman[16] says, regarding the largest area of anorthosite in the Rainy Lake region, that toward its western end "the green constituent becomes more important and the rock may be called a porphyritic gabbro."

The anorthosite-gabbro very commonly, and the typical Marcy anorthosite less commonly, locally exhibit more or less well developed foliation with exceedingly variable strikes. It is also important to note that granulation, which is so prevalent throughout the anorthosite body, shows many extreme variations, often in single outcrops. A striking example of variable degree of foliation and granulation is in the big ledge at the southwest end of Moose Island, in Lake Placid, where coarse grained, nongneissoid, typical anorthosite, with labradorite crystals up to 4 inches across, has in it a zone of much finer grained, granulated, clearly gneissoid anorthosite, the one grading into the other.

According to Kemp,[17] the anorthosites of the Elizabethtown-Port Henry quadrangle "vary from almost pure aggregates of plagioclase crystals through variations caused by increasing amounts of a pyyroxenic component." He further states that the pyroxene forms from 5 to 15 per cent of the Marcy anorthosite.

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[14] A. C. Lawson: Geol. and Nat. Hist. Sur. Minn., Bull. 8, 1893, pp. 1-23.
[15] N. H. Winchell: Geol. and Nat. Hist. Sur. Minn., Bull. 22, 1893, pp. 18-19.
[16] A. P. Coleman: Jour. Geol., vol. 4, 1896, p. 911.
[17] J. F. Kemp: N. Y. State Mus. Bull. 138, 1910, p. 28.

As a result of his work on the western side of the anorthosite body, Cushing[18] states that changes from typical anorthosite to anorthosite-gabbro, or even gabbro, "take place here and there within the general anorthosite mass."

Another variation from the anorthosite as a pure plagioclase rock consists in the dustlike (schillerization) inclusions of a dark mineral, probably ilmenite, in the labradorite. These are so numerous as to cause most of the labradorites to have a dark color. Thus even the plagioclase itself is not pure soda-lime feldspar. Adams[19] says, regarding the Morin anorthosite, that the "labradorite is filled with an infinite number of minute schillerization inclusions, which give to it a deep violet or nearly black color, so that the massive anorthosite is always very dark." Lawson describes similar numerous minute inclusions as occurring in many of the labradorites of the anorthosite of the Minnesota coast of Lake Superior.

Finally, in this connection, I would call attention to the presence of the very appreciable amount of potash in the typical anorthosite (see analysis above). Whether this potash exists in regular potash feldspar form or forms part of the labradorite proper, it is an additional proof that the anorthosite is not a practically pure mass of lime-soda feldspar.

In view of the facts, therefore, that the anorthosite averages fully 10 per cent of femic minerals visible to the naked eye; that its labradorites carry myriads of tiny inclusions of a dark mineral, and that the anorthosite contains a notable percentage of potash, is the mutual solution theory necessarily precluded, as argued by Bowen? Have we any proof that a rock with such a quantity and variety of constituents other than lime-soda feldspar could not have been, largely at least, molten as such? Is it safe to argue from experiments on very small amounts of rather pure melts under ordinary laboratory conditions that a rock like the Adirondack anorthosite could not have existed as a true magma? Bowen says that "a rock containing 10 per cent diopside (and 90 per cent plagioclase) could have had a maximum of 35 per cent liquid" in an artificial melt, and that in a natural melt "the probability is that the amount of liquid would be relatively somewhat larger on account of the presence of orthoclase in the liquid." But the Adirondack anorthosite would have formed a melt of notably more complicated composition than the artificial melt with 10 per cent diopside and under *deep-seated geologic conditions.* Is it safe to say, therefore, that such a melt may not have been a true magma with a high percentage of liquid?

Bowen argues that anorthosite, being made up almost exclusively of the

[18] H. P. Cushing: N. Y. State Mus. Bull. 115, 1907, p. 473.
[19] F. D. Adams: Geol. Sur. Can., Guide Book No. 3, 1913, p. 9.

single mineral plagioclase, must have been at an exceptionally high temperature if it was ever molten as such, but that anorthosite gives no evidence of ever having been hot enough to melt plagioclase. Bearing on this whole problem of the temperature relations of the anorthosite, we should keep in mind the following statements by Clarke:[20]

"Melting points are modified by various agencies within the earth, and it is not yet possible to strike a definite balance between the opposing forces. . . . Pressure tends to prevent the escape of dissolved vapors, and so to increase fluidity. . . . In the geological interpretation of the melting points (of minerals) there is one particularly dangerous source of error. We must not assume that the temperature at which a given oxide or silicate melts is the temperature at which a mineral of the same composition can crystallize from a magma."

Much yet remains to be learned about temperature relations of molten minerals and rocks within the earth, and we should, therefore, hesitate, on the basis of experiments on simple melts of practically pure minerals in the laboratory, to come to anything like definite conclusions regarding the temperature relations of magmas under deep-seated geologic conditions.

Another important consideration is the almost certain presence of very appreciable amounts of dissolved vapors, particularly water vapor, in the magma; for, as Clarke says, "one effect of the water would be to reduce the temperature at which liquidity could be maintained." Also the presence of about 2 per cent iron oxide in the typical anorthosite should not be overlooked, for it is well known that increase in the iron content lowers the melting point.

All things considered, therefore, I not only think it very reasonable to apply the mutual solution theory to the anorthosite, but also to regard the anorthosite to have existed in magmatic condition at a moderate temperature.

Since the foliation of the anorthosite is essentially a magmatic flow-structure, I believe it proves that, at the very least, large portions of the great mass of the anorthosite once possessed enough fluidity to permit distinct magmatic currents or movements. The significance of the foliation is not touched on by either Bowen or Cushing, but it is an important consideration. For a full discussion of flow-structure foliation in the Adirondack intrusives the reader is referred to my recent paper.[21] Only the salient points pertaining to the anorthosite are here presented. Even the typical Marcy anorthosite, almost entirely free from femic minerals,

[20] F. W. Clarke: U. S. Geol. Sur. Bull. 391, pp. 277 and 281.
[21] W. J. Miller: Jour. Geol., vol. 24, 1916, pp. 600-619.

not uncommonly exhibits a magmatic flow-structure foliation, the labradorite crystals having been strung out into crude parallelism in a yet molten portion of the rock. Not only was this interstitial liquid in sufficient quantity to permit the development of distinct magmatic flowage, but it was essentially *molten plagioclase*. It could have been nothing else. Hence we here have evidence directly opposed to Bowen's statement that the anorthosite was never at a temperature sufficiently high to melt plagioclase. The temperature was certainly high enough to keep some of the plagioclase in a molten condition, and such a temperature could not have been much lower than would have been necessary to keep all the plagioclase molten. This flow-structure foliation may well have developed during a late stage of magma consolidation, and it by no means proves that the whole mass of plagioclase was never molten as such during an earlier stage. At any rate, I believe that, in view of the composition, variability, and foliation of the anorthosite, Bowen does not allow for the presence of enough fluid in the cooling intrusive. How can the many notable variations of the anorthosite, often within very short distances, and the common occurrence of foliation, with exceedingly variable strikes and dips, be otherwise accounted for? It is utterly impossible for me to imagine how such features could have resulted from the sinking of plagioclase crystals, giving rise to a great mass of anorthosite, never, to at least a very considerable degree, molten as such.

But Bowen[22] says: "It seems reasonably possible both to obtain and to maintain almost any degree of heterogeneity as a result of the accumulation of crystals." He suggests that those portions relatively richer in plagioclase or in femic minerals accumulated in different portions of the (gabbroid) magma reservoir, and that they were, as partly crystalline masses, thrust into the positions they now occupy. Does Bowen mean that portions relatively rich in plagioclase, and others rich in femic constituents, tended to concentrate locally in many places throughout the cooling magma, from which positions they were, in many cases, shifted by magmatic flow? If so, I am inclined to look with favor on this explanation of the alternations of more or less clearly defined bands or zones of more gabbroid anorthosite with others of practically pure plagioclase. There are, as already pointed out, many portions, unusually rich in femic minerals, of irregular size, shape, and distribution throughout the anorthosite. These are not sharply separated from adjacent anorthosite much poorer in, or even practically free from, femic minerals. Some such more femic portions are foliated and others are not. They are almost certainly results of local differentiation whereby the femic constituents were here

[22] N. L. Bowen: Jour. Geol., vol. 25, 1917, p 237.

and there concentrated. Many of these portions, rich in dark constituents, show no evidence whatever of having been intruded or in any way thrust into the positions they now occupy, as Bowen suggests, but rather they appear to be differentiates practically *in situ*. In any case there must have been enough liquid in much of the rock to have allowed magmatic differentiation and flowage, and the liquid in the foliated zones of pure plagioclase rock must have been molten plagioclase.

I do not wish to imply, however, that the anorthosite as such was necessarily intruded in the form of a true magma to its present position, having been differentiated at a much lower level. Rather, it is probable that a gabbroid magma was the original intrusive which, either during the process of intrusion or after the magma came nearly to rest, or both, differentiated to give rise to the anorthosite which was then, at least in very considerable part, really molten. This matter is taken up more fully beyond under the caption, "Origin of the anorthosite by differentiation in a laccolith of gabbroid magma."

Though I believe the anorthosite as such to have been molten to a very considerable degree at least, it is by no means necessary to assume that it was ever completely molten with a high degree of fluidity, or even only a moderate degree of viscosity. The field facts best harmonize with the conception that the typical anorthosite as such may never have been completely molten, but that crystals of plagioclase originating in a gabbroid magma gradually developed, while the crystallizing femic minerals tended to separate themselves either by concentration locally within the general mass or by settling toward the bottom. Accordingly, as the anorthosite developed, it contained a decreasing amount of liquid, and this steadily became more viscous. On the one hand, then, it is quite possible, or even probable, as Bowen argues, that those portions of the great anorthosite body which are nearly pure plagioclase may never have been completely molten as such; but I maintain that even such portions must have contained at least considerable quantities of interstitial liquid. On the other hand, none of the field facts necessarily preclude the hypothesis that the whole mass of anorthosite may once have been completely molten, though not with a high degree of fluidity.

Before leaving this consideration of the significance of the variable composition of the anorthosite, emphasis should be placed on the fact that in many places its mass shows unmistakable evidence of having differentiation phases of anorthosite-gabbro, or even gabbro, while there is no positive evidence for differentiation phases of syenite or granite, as should be the case, according to Bowen's hypothesis. Cushing[23] says: "The gen-

[23] H. P. Cushing: Jour. Geol., vol. 25, 1917, p. 505.

eral differentiation *in situ* shown by the anorthosite is into anorthosite-gabbro and gabbro, and not into syenite." I am in hearty accord with this thesis. In all my work I have never found anything like positive proof for either syenite or granite as a differentiate of anorthosite.

Daly[24] says: "Most petrographers agree that anorthosite is a direct derivative of gabbroid magma," and that transitional forms and intimate relationships between anorthosite and gabbro are common phenomena. He gives illustrations from various regions; but he does not refer to any such relationship between syenite or granite and anorthosite. There are, however, certain rocks in the Adirondacks intermediate between syenite or granite and anorthosite-gabbro or anorthosite; but there is very strong evidence that such rocks were formed by assimilation of anorthosite by the later syenite or granite magma and not by differentiation *in situ*. The nature and origin of these rocks are rather fully considered beyond in this paper.

The chilled Gabbroid Border Facies and its Significance

GENERAL OBSERVATIONS

As already pointed out, the great body of Adirondack anorthosite has a more or less well developed gabbroid border facies. Not only is this border facies usually richer in femic minerals and notably finer grained than the typical Marcy anorthosite, but it is also usually more gneissoid with white instead of dark bluish gray feldspar. The Whiteface anorthosite above described is rather typical of this sort of rock.

DISTRIBUTION AND RELATION TO OTHER ROCKS

Cushing was the first to definitely recognize the existence of the gabbroid border facies on the western side of the anorthosite area. He regards it as a *chilled* gabbroid border of the anorthosite. Within the Long Lake quadrangle he maps a belt of this rock usually from 1 to 2 miles wide, and he states that there is a perfect transition from anorthosite through anorthosite-gabbro to gabbro. It is very important to note that he finds no evidence whatever for either the present or former existence of syenite intermediate between the true anorthosite and the gabbroid border facies. His map does, however, show one broad tongue of syenite to have locally cut out most of the border phase, this syenite containing several mappable inclusions of the gabbroid border rock.

My recent work in the Schroon Lake quadrangle very clearly shows the Whiteface anorthosite there to be a gabbroid border facies of the anor-

[24] R. A. Daly: Igneous Rocks and Their Origin, 1914, p. 324.

thosite, with perfect gradations from one into the other, and with no evidence whatever that syenite or granite was ever developed as a rock intermediate between the border phase and the true anorthosite. Though it has been notably cut into and partly assimilated by the syenite-granite body, a glance at the geologic map shows beyond question that this Whiteface anorthosite was formerly a continuous border phase of the body of Marcy anorthosite which occupies the whole northeastern one-third of the quadrangle. Three masses of the Whiteface anorthosite, from 1 to 2 miles wide and from 2 to 4 miles long, still lie against the Marcy anorthosite in their original undisturbed positions. There is strong evidence that this border phase was formerly at least 7 or 8 miles wide, because within that distance out from the typical Marcy anorthosite many smaller, widely scattered masses of rather gabbroid Whiteface anorthosite occur as mappable inclusions in the syenite-granite series all the way across the quadrangle. In other words, only remnants of the original border rock now remain. Further, since this border rock is notably finer grained than the Marcy anorthosite, it is very reasonable to interpret it as a chilled gabbroid border phase comparable in origin and position to Cushing's Long Lake border rock, though of lighter color and usually not so thoroughly gabbroid. The Schroon Lake quadrangle Whiteface anorthosite certainly averages more gabbroid than the Marcy anorthosite. It commonly carries 10 to 20 per cent dark minerals, but it is very variable, some phases containing only 5 per cent, or even less, and some more than 20 per cent.

My detailed survey of the Lake Placid quadrangle shows an unusually extensive development of Whiteface anorthosite, there being at least 40, and possibly 50, square miles, considerable areas being more or less effectually masked by glacial drift. One area alone is 10 miles long, with a maximum width of nearly seven miles. Among the other areas three are each several miles long. The Whiteface anorthosite of this quadrangle usually contains 10 to 12 per cent dark minerals, and it is therefore only a little more gabbroid than the Marcy anorthosite. But it varies greatly, some portions carrying almost no femic minerals and others 20 per cent or more. It has a very irregular distribution, not forming a definite fringe or outer margin of the Marcy anorthosite, as in most other districts. Further, it has been very extensively cut into by intrusions of the syenite-granite series, as explained in detail below. In no case, however, was any syenite found to be transitional between the Whiteface and Marcy anorthosites. Although the Whiteface anorthosite of the Lake Placid quadrangle is distinctly less gabbroid than most of the known border facies elsewhere, and its distribution is so irregular, it is, nevertheless, quite

certainly to be regarded as a border development of the great anorthosite body, as shown by its finer grained texture, perfect gradation into the Marcy anorthosite, and its very close similarity to definitely known border facies in other quadrangles.

I have also observed Whiteface anorthosite as a border facies of the Marcy anorthosite in both the Newcomb and Ausable quadrangles, but detailed surveys of these have not yet been made.

Kemp's map of the Elizabethtown and Port Henry quadrangles shows a very definite border development about the large mass of anorthosite there exposed. This border development he maps as "basic anorthosite and related types." Judging by his description, much of it is Whiteface anorthosite, though more gabbroid than that of the Lake Placid quadrangle. This border zone is from one-half to 2 miles wide. Locally it has been cut into or completely cut out by syenite. In the western part of the town of Moriah the geologic map shows two small areas of the border facies completely surrounded by syenite and separated 1 and 2 miles, respectively, from the continuous border. I interpret these as simply remnants of the once much more extensive border facies which became enveloped in the invading syenite magma. It is therefore not unreasonable to consider a good many square miles of the border facies to have been cut out or displaced by the big body of syenite shown on the map. It is very clear from Kemp's description and map that no syenite exists as a rock intermediate between the border facies and the typical anorthosite, but rather the border rock grades into the Marcy anorthosite.

Dr. Ogilvie[25] says, regarding the anorthosite of the Paradox Lake quadrangle, that "the dark silicates are more abundant in the peripheral portion of the intrusion," and that on one hill near the border a very white variety of anorthosite occurs, though no details are given and such rocks are not separately represented on the geologic map. But, judging by the prominence of the border facies in both the adjacent Schroon Lake and Elizabethtown quadrangles, such border types are probably well represented in the Paradox Lake quadrangle.

Daly,[26] after considering a number of anorthosite areas, states that "the greater anorthosite bodies usually have a well developed contact phase of more or less typical gabbro or norite. In the interior each mass becomes rapidly more feldspathic, and for most of the outcrop the rock is monotonous anorthosite." But he makes no mention of any development of syenite between any border (contact) facies and true anorthosite, such as is required by Bowen's hypothesis.

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[25] I. H. Ogilvie: N. Y. State Mus. Bull. 96, 1905, p. 499.
[26] R. A. Daly: Igneous Rocks and Their Origin, 1914, p. 327.

THE BORDER FACIES BOTH AN OUTER AND AN UPPER LIMIT OF THE ANORTHOSITE

Cushing[27] maintains that the gabbroid border facies in its present position marks the outer limit of the great body of Adirondack anorthosite, or, in other wards, "that the chilled border determines for us the original size of the mass at the depth represented by the present erosion surface," and that therefore the "anorthosite mass can not be regarded as spreading out underneath the outlying syenite masses and extending throughout the (Adirondack) region." This is a very important point and, since Cushing's argument in support of it seems to me to be conclusive, it is unnecessary to repeat it here. Though I agree with Cushing's main argument, there is one slight modification, namely, that the borders of the anorthosite body have in some districts, like the Schroon Lake and Lake Placid quadrangles, been so cut out or cut to pieces by the syenite-granite intrusion that the full original extent of the anorthosite is not now shown. This is a matter of some miles in certain districts.

There is strong evidence that the chilled gabbroid border facies also developed as an *upper* limit which formerly existed as a cover resting directly on the whole great mass of anorthosite rather than merely as an *outer* limit, as Cushing suggests. Thus, as already pointed out, the Whiteface anorthosite of the Lake Placid quadrangle does not exist merely as a definite fringe around the outer margin of the Marcy anorthosite. I have there found typical Whiteface anorthosite fully 14 or 15 miles within the present border of the anorthosite area, and inclusions in the syenite-granite series outside the general anorthosite area show that the Whiteface anorthosite formerly extended at least a few miles farther out than the present boundary. One area of Marcy anorthosite, 12 miles long within the Lake Placid quadrangle and extending an unknown distance into the Ausable quadrangle, is flanked on either side by Whiteface anorthosite. It is hard to resist the suggestion that Whiteface anorthosite formerly covered this whole mass of Marcy anorthosite. There is thus a distinct difficulty in the way of considering this Whiteface anorthosite merely an outer border facies. But if we do so regard this border facies, we are forced to conclude that it is exceedingly thick—that is to say, fully 10 or 15 miles—the width of the area containing Whiteface anorthosite representing practically the thickness of the border phase. This is scarcely possible. If, however, we consider the Whiteface anorthosite of the quadrangle to mark an upper limit of the great anorthosite body, but now partially removed by erosion and partly cut into by the

[27] H. P. Cushing: Jour. Geol., vol. 25, 1917, p. 506.

syenite-granite series, not nearly so great a thickness need be assumed. On this view a vertical thickness of fully 3,000 feet is actually exposed in Mount Whiteface, and how much more should be added to make up for the upper portion removed by erosion is of course unknown. Probably little or none is to be added to the bottom, because Marcy anorthosite outcrops near the base of the mountain.

The Schroon Lake quadrangle yields similar evidence, since, as above pointed out, the border facies (Whiteface anorthosite) there formerly extended fully 7 or 8 miles out beyond the present margin of the Marcy anorthosite, as indicated by numerous inclusions in the syenite-granite series. In this connection a very interesting inclusion of typical Marcy anorthosite in the granite, over 6 miles out from the present border of that anorthosite, may be reasonably interpreted as a fragment caught up in the granite magma at a lower level (below the Whiteface anorthosite cover) and carried upward to its present position. In any case it is certain that Marcy anorthosite existed that far out. Within the Schroon Lake quadrangle I found no Whiteface anorthosite within the large area of Marcy anorthosite there exposed.

Kemp's Elizabethtown map shows a prominent belt of gabbroid border anorthosite extending several miles northward into the Marcy anorthosite country and to an unknown distance into the adjoining quadrangle. This belt may be plausibly explained as a remnant of a once widespread cover over at least the outer portion of the great body of Marcy anorthosite. That this border facies once extended considerably farther beyond the present limits of the continuous body of anorthosite is proved in two ways, namely, by the occurrence of the two large inclusions of border anorthosite well within the syenite and by the complete cutting out of the border by the syenite in places.

Cushing's Long Lake map represents one small area of gabbroid border anorthosite surrounded by Marcy anorthosite more than a mile in from its margin.

Unless definite areas of this basic chilled border facies are found far within the great anorthosite area, positive proof that such a border facies once existed as a cover over the whole will be wanting. But such a border facies, if once present as a universal cover, would show few, if any, remains far within the great anorthosite area because of the widespread and deep erosion to which the region has been subjected.

In short, the evidence from the outer portions of the great anorthosite body strongly supports the view that a chilled gabbroid border facies should be regarded as having formerly existed as a cover resting directly on the whole mass of Marcy anorthosite. The evidence from the interior

is negative, but nothing in the field is opposed to this view. I do not believe this view precludes Cushing's conception of an *outer* chilled border of the anorthosite, provided we regard the anorthosite as a great laccolithic intrusive body (see figure 3), all over which a border facies developed as an *upper* limit, and at the margins of which a border facies developed at the same time as the outer limit. I therefore agree with Cushing that the area of anorthosite shown on the State geologic map shows practically "the original size of the mass at the depth represented by the present erosion surface," and that the anorthosite can not extend out to, or even close to, the margins of the whole Adirondack region.

Although Bowen, in his second paper, admits the probable existence of a chilled gabbroid border facies, his conception is essentially different from mine in two important respects: First, he believes the border facies represents wholly an upper limit of a laccolithic intrusive body as large as the whole Adirondack region, and, second, he maintains that the syenite-granite series developed between the border facies and the true anorthosite still lower down, and that much of this syenite-granite series must still exist in that position, though much of it was later by reintrusion forced through the gabbroid cover. In the light of the field facts above presented, I am decidedly opposed to these views of Bowen.

SIGNIFICANCE OF THE CHILLED BORDER FACIES

According to Bowen, the femic constituents of a great gabbroid magma as wide as the Adirondack region first separated (or sank) by gravity, while the plagioclase crystals (then in the form of basic bytownite) remained practically suspended. Then, at a later stage, when the liquid became light enough, plagioclase crystals (then in the form of labradorite) accumulated by sinking, thus giving rise to the mass of the anorthosite, leaving the overlying liquid of such composition as to yield syenite or granite. In his first paper Bowen does not consider the development of a chilled border of the Adirondack anorthosite. In his second paper, by way of reply to Cushing, he modifies his idea of the stratiform arrangement of the igneous complex by considering the development of a "gabbroid chilled upper portion of a laccolithic mass extending far beyond the limits of the present exposure." Directly under the chilled border, according to Bowen, the great body of syenite-granite developed; still lower down the typical anorthosite formed, and at the bottom pyroxenite and gabbro.

Now, Professor Cushing and I both have demonstrated that the great body of anorthosite has a gabbroid chilled border which can not possibly extend far out beyond the present exposure of the anorthosite, and with

absolutely no evidence for the existence of syenite or granite formed as a differentiate between the outer and upper border facies and the lower typical anorthosite. It is therefore evident that the field facts are directly opposed to Bowen's hypothesis of the origin of the anorthosite by the settling of plagioclase crystals. There simply is nothing from which they could have settled, since the chilled border grades perfectly into the true anorthosite, and the border phase is really only more or less gabbroid anorthosite. This must be true, whether we regard the chilled border as simply an outer facies, as advocated by Cushing, or as both an outer and an upper facies of a laccolith, as I have tried to establish above. In other words, in view of the existence of this chilled border without intervening syenite, it is entirely out of the question to interpret the Adirondack igneous complex as even in a general way a "sheetlike mass with syenite above and anorthosite below," as required by Bowen's hypothesis.

Relation of the Anorthosite to the Grenville Series

Grenville-Anorthosite Mixed Gneisses

Within the Lake Placid quadrangle I have discovered a number of areas of intimately associated Grenville strata and Whiteface anorthosite. Bowen[28] lays special emphasis on the apparent absence of such areas, and remarks: "In many of the mapped quadrangles it has been necessary to use a color to represent a mixture of Grenville and syenite that defies separate mapping," and that "the anorthosite areas, on the other hand, are very different." Since the intimately associated Grenville and anorthosite rocks have an important bearing on the problem of the anorthosite, I shall describe several of the largest areas somewhat in detail. In many portions of these areas the Grenville has been cut to pieces by dikes and bands of Whiteface anorthosite; in other places the Grenville has been truly injected by the anorthosite, and in many places inclusions of the Grenville occur. In some places the Grenville predominates and in others the anorthosite, but the two rocks are too closely associated to be at all satisfactorily separately represented on the geologic map. It is important to bear in mind that the Whiteface anorthosite, in the areas now to be described, is mostly fully as free from femic minerals as the typical Marcy anorthosite, and in a number of places it is nearly pure plagioclase.

The largest area within the Lake Placid quadrangle is over 3 miles long and lies between Keene and Upper Jay. For most part the rocks are Grenville hornblende gneiss and pyroxene gneiss which have been cut

[28] N. L. Bowen: Jour. Geol., vol. 25, 1917, pp. 222-223.

to pieces by intrusions of Whiteface anorthosite, the Grenville and the anorthosite nearly always being clearly recognizable as such. Very distinct small inclusions of Grenville gneiss in the anorthosite were noted in various ledges, particularly along the road between 1 and 2 miles south of Upper Jay; by the road 1¼ miles southwest of Upper Jay, and 2¼ miles due north of Keene, in the western corner of the large area.

Another type of mixed gneisses from the large area above mentioned is of particular interest. The best place to study these rocks is in and around the quarry by the road 3¼ miles north of Keene. In the quarry the rocks are Grenville hornblende and pyroxene gneisses more or less intimately involved with nearly pure plagioclase Whiteface anorthosite. Much of the rock is a true injection gneiss, the Grenville having been so intimately penetrated by the anorthosite magma that the small hornblende and pyroxene crystals were mostly separated from each other and enveloped in the molten mass parallel to the magmatic currents, thus giving to the resulting gray, medium grained rock a clearly defined foliation. Some portions of this rock are richer in dark minerals than others, and some portions show lenslike masses or bunches of the dark minerals as distinct inclusions, about 2 inches long, which were enveloped in the magma without being broken up. This rock contains occasional light bluish gray labradorite crystals up to an inch in length and numerous grains of titanite. A thin section reveals the following mineral percentages: Andesine to labradorite, 58; green monoclinic pyroxene, 30; green hornblende, 10; titanite, 1½, and a very little zircon. Another slide shows several per cent quartz in a narrow band. Locally, where the anorthosite greatly predominates, the rock is much coarser grained and the dark minerals are more irregularly arranged, so that the foliation is not so pronounced. It is very evident that the Grenville of this locality has been more or less intimately injected by Whiteface anorthosite magma, but there is no indication whatever of actual digestion or assimilation of the Grenville by the magma, the crystals and fragments of Grenville always showing sharp contacts against the enveloping anorthosite.

The area, 2 miles long, on the southern end of Wilmington Mountain, contains mostly Whiteface anorthosite, but nearly every outcrop has in it so many inclusions of Grenville, chiefly green pyroxene gneiss, that it has seemed advisable to map this as an area of mixed rocks. Injection gneisses like those above noted were not observed.

Along the road just east of Franklin Falls there are some instructive ledges of Grenville and Whiteface anorthosite mixed gneisses. One phase of this rock is white, medium grained Whiteface anorthosite (practically all plagioclase) containing approximately 20 per cent irregular lenslike

masses and bunches of dark monoclinic pyroxene crystals, these masses ranging in size from mere specks to an inch or two long and roughly parallel, causing the rock to exhibit a crude foliated structure. Closely associated with this rock is a true injection gneiss which is gray, medium grained, and clearly foliated. A thin section reveals the following mineral percentages: Andesine to labradorite, 82; hornblende, 9; both green and colorless pyroxenes, 7½; biotite, 1, and ilmenite, one-half. Still another phase of the rock from the same ledge is very similar, but it is finer grained and contains several per cent of pale red garnets in small scattering grains. It is very evident that these several facies together represent a border phase of the considerable body of adjacent Grenville which has been penetrated more or less intimately by Whiteface anorthosite magma.

It might be argued that the above described intimate associations are not very significant because it is Whiteface, rather than Marcy, anorthosite involved with the Grenville. Now, although some inclusions of Grenville in Marcy anorthosite are known (see below), it does, nevertheless, appear to be true, as Bowen maintains, that Grenville and Marcy anorthosite are never very intimately associated. But this is readily explained, first, because the outer and upper (border) portion, rather than the inner portion, of the great intrusive came into contact with, and more or less cut into, the Grenville, and, second, because, as pointed out elsewhere in this paper, there is good reason to think that the inner or Marcy anorthosite portion of the intrusive was probably too viscous to have had much power of penetration. Furthermore, opportunity for observing the effect of Marcy anorthosite on Grenville is very restricted, because the Grenville has been almost, if not completely, removed from the interior of the great anorthosite area.

The occurrences above described are very significant, since most of the Whiteface rock which has so intimately penetrated the Grenville is just as truly anorthosite as the typical Marcy anorthosite. Much of it is, in fact, made up almost entirely of pure white plagioclase. In most of these mixed gneiss localities in the Lake Placid quadrangle the field evidence strongly points to the occurrence of the nearly pure plagioclase Whiteface anorthosite far under its surface or, in other words, not far from the outside or upper limit of the Marcy anorthosite. In such positions the border facies would scarcely be any more gabbroid than the typical Marcy anorthosite, and locally it might even carry fewer femic minerals, as is the case locally within the Marcy anorthosite. The very occurrence of the nearly pure plagioclase anorthosite as numerous bands or dikes in or as injections into the Grenville proves the rock to have once been in a true magmatic condition, either wholly, or at least largely, molten as such.

In any case the evidence is very clear that much, if not all, the plagioclase of such nearly pure plagioclase rocks was actually in a fluid condition, and thus we have more proof opposed to Bowen's statement that the anorthosite gives "no evidence of having been raised to the temperature requisite to melt plagioclase." The rocks above described also make it certain that a very appreciable amount of true anorthosite, much of it very low in femic constituents, is just as intimately associated with Grenville as is the syenite and in exactly the same manner. The plain inference is that such anorthosite was once as highly fluid as the syenite. Further, if so much plagioclase of such nearly pure plagioclase rock was actually fluid, is it unreasonable to suppose that the great body of even more impure Marcy anorthosite may once have been a true magma with a high percentage of liquid?

INCLUSIONS OF GRENVILLE IN ANORTHOSITE

Inclusions of Grenville rocks in the Whiteface anorthosite are common. They comprise various kinds of the Grenville strata and range in length from an inch or two to a mile or more. Excellent examples of large ones occur in the vicinity of Keene and Franklin Falls, as shown on the forthcoming Lake Placid geologic map.

Mention has already been made of the great number of small inclusions of Grenville gneiss in the nearly pure plagioclase Whiteface anorthosite of the mixed gneiss area at the southern end of Wilmington Mountain of the Lake Placid quadrangle. Other interesting inclusions occur in the walls of The Flume, near Wilmington, in the same quadrangle. The rock is medium to moderately coarse grained, consists largely of pinkish labradorite, through the mass of which are scattered 2 to 15 per cent femic minerals, and is in places moderately gneissoid. Some very distinct small, drawn out, or lenslike inclusions of Grenville pyroxene gneiss occur, a careful study of which in the field having led me to the suggestions that the much smaller (one-quarter to one-half inch) numerous lenslike masses which constitute most of the femic constituents of the rock are really very small fragments of Grenville gneiss which were caught in the intruding magma of nearly pure plagioclase anorthosite and roughly arranged parallel to the magmatic lines of flowage, thus giving rise to the gneissoid structure.

Inclusions of Grenville in the Marcy anorthosite are much more uncommon. In the Lake Placid quadrangle I have noted such in but one locality, 2 miles northeast of Keene, where several sharply defined inclusions (each several feet across) of Grenville rocks, including limestone, are plainly embedded in typical Marcy anorthosite. In the Schroon Lake

quadrangle I found none at all. Cushing shows none on his Long Lake map.

On his Elizabethtown-Port Henry map, Kemp represents an area of Grenville, three-quarters of a mile long, completely surrounded by Marcy anorthosite. Several other small areas are shown to lie between the basic border and the Marcy anorthosite. Kemp has also described some inclusions of Grenville (too small to be mapped) in anorthosite, presumably the Marcy type, as occurring in the Elizabethtown quadrangle. He has also observed many small inclusions of Grenville gneiss in massive anorthosite, presumably the Marcy type, in the vicinity of Keene Valley, in the Mount Marcy quadrangle.[29]

The few known inclusions of Grenville in Marcy anorthosite, above described, all lie close to its border facies. It is, then, a striking fact that the Whiteface (border) anorthosite contains many inclusions and considerable areas of Grenville, while the Marcy anorthosite contains very few, and these near the border facies. The explanation is simple. Only the border phase of the great body of intruding magma actually came in contact with or broke into the country rock (Grenville) to any notable extent. Masses of Grenville, large and small, were torn from both the sides and roof of the magmatic chamber. Many of these fragments sank into or were enveloped by the border facies, which I regard as having developed both as an outer and an upper limit, while but few of them ever sank or were forced far enough into or through the border phase of the intruding magma to reach even the outer portion of what developed into typical Marcy anorthosite. Now, the few known inclusions of Grenville in the Marcy anorthosite are close to the border phase and hence close to its inner (or lower) limit. Theoretically, at least, it is not impossible to imagine some Grenville fragments farther within the Marcy anorthosite, where the border facies was relatively thin, or due to shifting of some of the typical anorthosite magma closer to the upper or outer limit of the magma chamber by magmatic currents during a later stage of consolidation. Possibly the small inclusions of Grenville in anorthosite in the vicinity of Keene Valley above referred to are to be explained in this way.

It is therefore easy to understand why no inclusions of Grenville are definitely known well within the great body of Marcy anorthosite, and this in spite of much detailed work, because not only the upper or border phase of the anorthosite, which probably contained many inclusions, but also much of the upper portion of the Marcy anorthosite have been removed by deep and widespread erosion over the region.

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[29] J. F. Kemp: Bull. Geol. Soc. Am., vol. 25, 1914, p. 47.

The inclusions of Grenville are significant in yet another way. Since many of them occur well within or toward the inner margin of the Whiteface anorthosite, or even just beyond it in the outer portion of the body of Marcy anorthosite, it is evident that the Grenville inclusions, both small fragments and larger masses, must either have been torn off by and enveloped in a very active anorthosite intrusive magma, or they must have settled through at least a few thousand feet of anorthosite which was in a pretty highly fluid state. It might be argued that these inclusions were enveloped by or sank well into an original gabbroid magma, from which, by settling of the femic constituents due to gravity, the anorthosite, never molten as such, developed. But, on this view, why should the femic constituents on crystallizing have settled, when the inclusions, many of them made up of heavy femic minerals, remained suspended? Again, it should be remembered that many of the Grenville fragments show an arrangement, even in almost pure plagioclase anorthosite, parallel to what I confidently believe to be a magmatic flow-structure foliation. This argues for a former true magmatic condition of this sort of anorthosite with a very considerable amount of liquid—that is to say, enough to have permitted distinct magmatic currents. Now, if this practically pure plagioclase anorthosite once possessed such a high degree of fluidity, is it out of the question to argue that the notably more impure general body of Marcy anorthosite may once have been in a true magmatic condition?

The anorthosite of the Rainy Lake district of Ontario furnishes important corroborative evidence. That this rock was once in magmatic form and very actively intrusive is Coleman's[30] view, stated as follows:

"Frequently portions of chloritic or sericitic schist have been inclosed by the anorthosite (consisting of fully nine-tenths plagioclase), showing its post-Keewatin age, and occasionally a green massive rock, apparently weathered diabase, is seen, probably portions of massive Keewatin rocks swept off by the molten anorthosite."

DIKES OF ANORTHOSITE IN GRENVILLE

Bowen says,[31] regarding the Adirondack anorthosite, that none of the "investigators who have studied the area have found a single dike of nearly pure plagioclase in the surrounding rocks," and that "it seems to be a reasonable conclusion that this material was incapable of being injected into the older rocks." He admits that anorthosite-gabbro invades the Grenville in places. These statements call for consideration.

[30] A. P. Coleman: Jour. Geol., vol. 4, 1896, p. 911.
[31] N. L. Bowen: Jour. Geol., vol. 25, 1917, p. 220.

I admit that there is no definitely known example of a true dike of typical Marcy anorthosite in the older rocks. Now, any such dikes must be looked for in the Grenville rocks because these were the only ones present at the time of the intrusion. But, as already pointed out, Marcy anorthosite and Grenville are known to come together in very few places, and these are where mere inclusions of Grenville (some of mappable size) occur. It is therefore not at all conclusive to say that because dikes of Marcy anorthosite are unknown this anorthosite was never molten as such. It should also be remembered that I maintain that the Marcy anorthosite was once either wholly, or at least largely, molten, but in a rather viscous condition, and hence not so favorable for intrusion as small dikes into the few small bodies of Grenville which it is known to have enveloped.

With the border facies of the anorthosite the case is notably different, because it was the outer and upper portion of the great intrusive body which came into direct contact with the Grenville country rock, and hence was favorably situated for cutting into and enveloping masses of Grenville. As above shown, particularly in the areas of Grenville and Whiteface anorthosite mixed rocks of the Lake Placid quadrangle, dikes and bands of Whiteface anorthosite in Grenville commonly occur and many of them are sharply defined. It should be repeated with emphasis, that some of these dikes and bands are certainly fully as free from femic minerals as much of the very typical Marcy anorthosite. This field evidence, therefore, does not support Bowen's statement regarding absence of dikes of nearly pure plagioclase.

In the other quadrangles which have been mapped more or less in detail actually observed contacts between Grenville and anorthosite are very rare and the existence of anorthosite dikes is neither proved nor disproved. In Franklin County, Cushing[32] has found that "the few contacts exposed show the anorthosite cutting them (Grenville and other older gneisses) and sending tongues into them," but the exact kind of anorthosite is not stated.

Relation of the Syenite-granite Series to the Anorthosite

SYENITE-GRANITE SERIES DISTINCTLY YOUNGER THAN THE ANORTHOSITE

According to Bowen, the syenite-granite series and the anorthosite are not distinctly separate intrusives, but both formed as differentiates from a single great body of intruded gabbroid magma. He[33] says: "I think it must be admitted that in much of the quadrangle work the syenite is

[32] H. P. Cushing: N. Y. State Mus. Bull. 95, 1905, p. 307.
[33] N. L. Bowen: Jour. Geol., vol. 25, 1917, p. 511.

considered later than the anorthosite solely on the basis of his (Cushing's) findings in the Long Lake quadrangle." Now, Cushing and I both believe the syenite-granite series to be distinctly later, and I have found abundant evidence in support of this view in both the Lake Placid and Schroon Lake quadrangles. I feel confident that if Bowen had known of these important additional field facts, and he had seen my detailed geologic maps, he would not have been so much inclined to minimize the evidence for the distinctly later intrusion of the syenite-granite series. This evidence will now be rather fully considered.

DIKES OF SYENITE AND GRANITE IN ANORTHOSITE

Some years ago, in his report on the geology of the Long Lake quadrangle, Cushing[34] showed that the syenite there is distinctly younger than the anorthosite. In one small area several narrow, well defined dikes of syenite cut the typical Marcy anorthosite, one of these dikes being several miles within the border of the great anorthosite body. He presents the evidence in detail. Having seen some of these dikes, I fully agree with Cushing that the evidence is decisive and it is unnecessary to repeat details here. In the same report Cushing states that one of the small outlying masses of anorthosite is "definitely cut by syenite which sends dikes into it."

As a result of the surveys of the Lake Placid and Schroon Lake quadrangles, various excellent examples of narrow tongues or dikes of syenite and granite cutting anorthosite have come to light. Since these constitute important evidence regarding the relation of the syenite-granite series to the anorthosite, they will be described somewhat in detail.

One mile south of Morgan Pond (Lake Placid quadrangle), on a prominent spur of Wilmington Mountain, two dikes of quartz syenite clearly exposed for 50 or 60 feet cut through a big bare ledge of typical Whiteface anorthosite (see figure 1). The dikes are from 10 to 20 feet wide, and they are quite certainly offshoots from the considerable body of quartz syenite which grades into granite to the west. As would be expected in such narrow dikes, the syenite is finer grained than usual, but otherwise it is quite normal. The dike rock is slightly gneissoid and its contacts against the anorthosite are not perfectly sharp, there having been, apparently, a little assimilation along the borders.

Along the brook, three-quarters of a mile west of The Flume (Lake Placid quadrangle), a dike of quartz syenite 20 feet wide cuts typical Marcy anorthosite. This dike is an offshoot from the considerable body of similar syenite extending southwestward.

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[34] H. P. Cushing: N. Y. State Mus. Bull. 115, 1907, pp. 480-484.

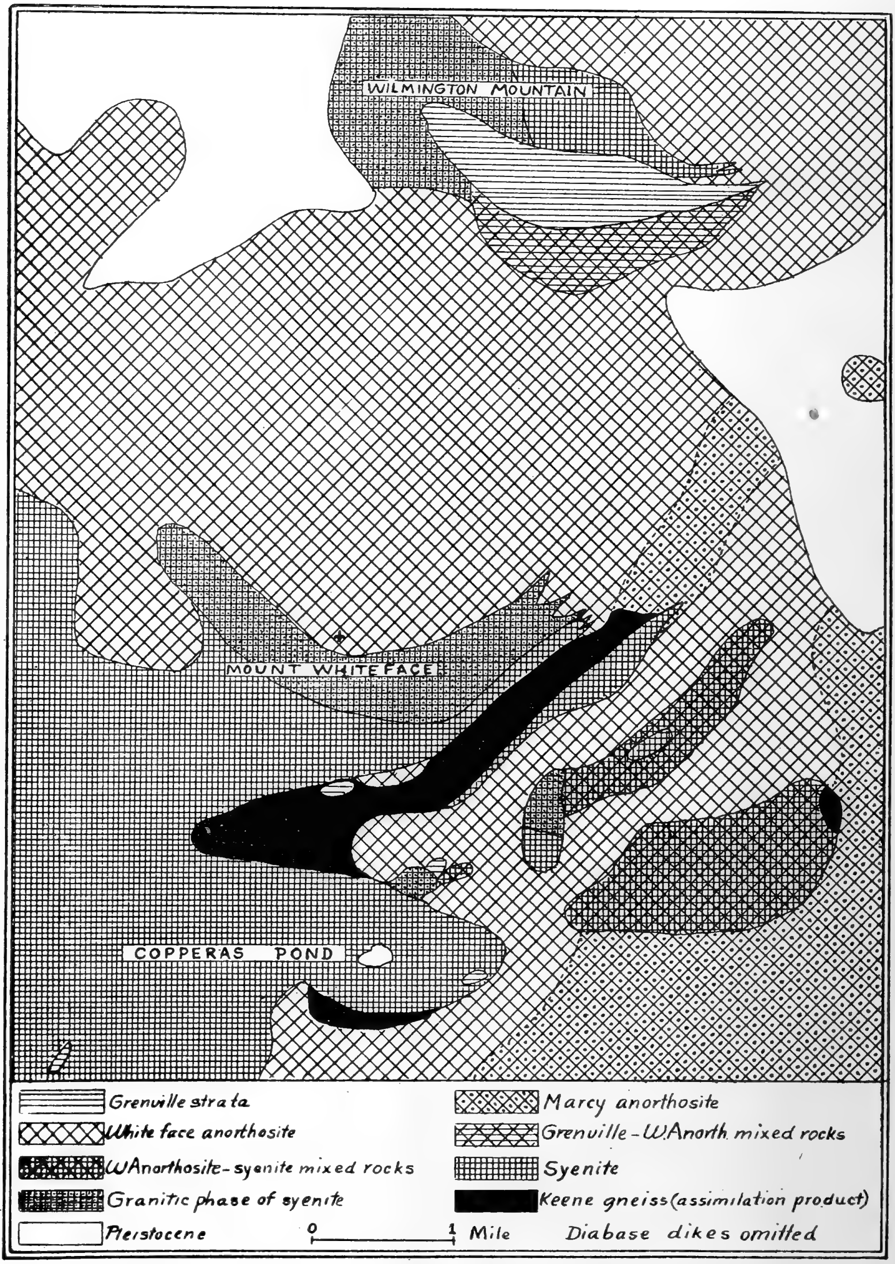

FIGURE 1.—*Geologic Map of central Portion of Lake Placid Quadrangle*

On the mountain spur, 1¼ miles northeast of the summit of Little Whiteface Mountain (Lake Placid quadrangle), a number of tongues of granite cut the Whiteface anorthosite. The relations are very clear in the big bare ledges, the dikes being small tongues of the large body of granite across the southern face of Mount Whiteface. One of these tongues is only 20 feet wide, but the others are each a number of rods wide at the summit of the mountain ridge. They pinch out eastward. The granite is clearly gneissoid and it contains several per cent hornblende. Immediately to the south several dikes of granitic syenite, none over 3 feet wide, sharply cut Whiteface anorthosite. Most of the anorthosite cut by these dikes is white and nearly free from femic minerals, and hence probably far within the border facies—that is to say, close to the outer part of the Marcy anorthosite (see figure 1).

During the summer of 1917 my work in the Schroon Lake quadrangle brought to light still other examples, these all being dikes or small tongues of granite, which is there the more prominent member of the syenite-granite series. One of these is well shown by the road 1½ miles west of Boreas River, where a dike of granite 5 feet wide cuts rather femic Whiteface anorthosite. Another is a dike of typical pinkish gray granite, 25 feet wide, 1 mile west of the summit of Sand Pond Mountain. It sharply cuts Whiteface anorthosite, which lies near, and closely resembles Marcy anorthosite. Both dikes last mentioned are quite certainly offshoots from large bodies of typical granite which in a general way cut into the marginal portion of the great body of anorthosite. Still another dike of granitic syenite or granite cuts Marcy anorthosite just north of the summit of Texas Ridge.

I am confident that many other clearly defined dikes of syenite and granite in anorthosite exist in the Lake Placid and Schroon Lake quadrangles, but it is difficult to locate and demonstrate their presence in such a rough, densely forested country. It should be emphasized that at least some of these dikes cut right into the typical Marcy anorthosite. The evidence, therefore, from the dikes, that the syenite-granite series is distinctly younger than the anorthosite, is very strong and by no means confined to the Long Lake quadrangle.

Dresser[35] states that on the south side of the Canadian Saguenay anorthosite border syenite grades into granite which clearly cuts the anorthosite, thus exactly corroborating similar evidence from the Adirondacks.

Coleman[36] says, regarding the largest area of anorthosite in the Rainy Lake district, that the granite "has sent apophyses into the anorthosite

[35] J. A. Dresser: Bull. Geol. Soc. Am., vol. 28, 1917, p. 155.
[36] A. P. Coleman: Jour. Geol., vol. 4, 1896, p. 911.

and has pushed its way through a schist conglomerate containing pebbles and boulders of quartz-porphyry, sandstone, green schist, and occasionally also anorthosite quite like some facies of the adjoining mass. Apparently a long interval separated the anorthosite eruption from that of the anorthosite." Not only is this granite distinctly later than the anorthosite, but also there is no evidence of gradation of anorthosite into granite or even syenite.

BROAD INTRUSIVE TONGUES OF SYENITE AND GRANITE IN ANORTHOSITE

The broad tongues of syenite and granite extending, in a number of places for miles, into the great body of anorthosite furnish perhaps even more impressive evidence than the dikes that the syenite-granite series is really younger than the anorthosite.

Regarding an excellent example of such an intrusion of syenite into the anorthosite of the Long Lake quadrangle, Cushing[37] says: "It cuts into the anorthosite for a depth of 2 miles, cutting out much of the gabbro and anorthosite-gabbro border, though these appear in full width on both sides of the salient." This intrusive tongue is from 1 to 3 miles wide.

In the Schroon Lake quadrangle I have mapped a tongue of granite from 2 to 4 miles wide which extends into the anorthosite for fully 4 miles, reaching all the way through the border facies and into the Marcy anorthosite. A large intrusive mass of still later gabbro appears within this salient. In two places I have found small dikes as offshoots of the salient sharply cutting the anorthosite.

My Lake Placid map shows a fine example of a tongue of syenite grading into granite and extending for several miles into the Whiteface anorthosite across the southern portion of Wilmington Mountain. On the south a considerable body of Grenville lies in contact with this intrusive tongue. This tongue, with a width of 1½ miles on the west, gradually becomes narrower toward the east, till finally it sends the dikes of syenite, already described, into the anorthosite.

A great body of syenite, with locally developed granitic facies, varying in width from 1 to 6 miles, extends into the anorthosite area 13 miles across the Lake Placid quadrangle, and thence for an unknown distance into the Mount Marcy quadrangle. I confidently believe this to be intrusive into the anorthosite, my reasons being stated beyond in this paper. This big tongue of the syenite-granite series extends much farther into the great body of anorthosite than any other thus far mapped in detail.

[37] H. P. Cushing: Jour. Geol., vol. 25, 1917, p. 506.

Another body of syenite, shown in part only in the southeastern portion of the Lake Placid quadrangle, extends northeastward into the Ausable quadrangle and possibly connects with the great tongue of the syenite-granite series which extends southward for some miles into the anorthosite of that quadrangle, but this has not yet been proved.

Kemp's Elizabethtown-Port Henry map shows the syenite to cut out the whole border facies of the anorthosite in several places. About 2½ miles northeast of Mineville a tongue of syenite only one-fourth of a mile wide extends almost a mile into and through the border phase. These facts, together with the occurrence of the small mappable masses of border anorthosite in the syenite 1 and 2 miles, respectively, from the main area, make it seem reasonable to regard the whole body of syenite shown on the map as a great intrusive salient which cuts out the anorthosite body for miles.

SYENITE-GRANITE AND ANORTHOSITE MIXED GNEISSES

Areas of mixed rocks of this sort represent masses of Whiteface anorthosite which have been more or less shot through and cut to pieces by syenite or granite. Locally the rocks exhibit their characteristic features, but they are too intimately associated to be separately shown on the geologic map.

In the Lake Placid quadrangle two areas of such rocks, each about 2 miles long, lie far within the general anorthosite area southwest of Wilmington (see figure 1). Irruptive contacts of syenite against Whiteface anorthosite are not uncommon. These contacts are usually not perfectly sharp, as though slight fusion of the anorthosite by the intruding magma took place along the immediate borders between the rocks. The intricate relationship of these rocks is very evident.

In the Schroon Lake quadrangle I have been obliged to map a very irregular-shaped area of some 4 or 5 square miles of similar mixed rocks. In this case the Whiteface anorthosite is badly cut to pieces mostly by granite, but also by some syenite.

INCLUSIONS OF ANORTHOSITE IN THE SYENITE-GRANITE SERIES

The inclusions of anorthosite in the syenite-granite series furnish very strong evidence that the syenite-granite body is an intrusive distinctly separate from and later than the anorthosite. Such evidence is scarcely, if at all, touched on by Bowen, probably because few examples of such inclusions were known to him, these being the ones within the Long Lake quadrangle.

It seems evident from a glance at my Schroon Lake geologic map that the anorthosite once extended out as a continuous broad belt at least 7 or 8 miles beyond the present margin of the Marcy anorthosite, because within that distance from the Marcy anorthosite there are many inclusions of anorthosite (many of sufficient size to be mapped) in the syenite-granite series all the way across the quadrangle. In other words, only mere remnants of the former anorthosite here remain. With the exception of one locality, these are all inclusions of Whiteface anorthosite. The exceptional locality is of particular interest. It is on top of the small mountain of typical granite a little over a mile north-northeast of Pat Pond. One patch of the granite 12 feet across contains large dark bluish gray labradorites an inch or more across and several small pieces of typical Marcy anorthosite as distinct inclusions mostly arranged roughly parallel to the foliation of the granite. Immediately around the larger fragments the granite shows fine magmatic flow-structure. A similar exposure occurs close by. My interpretation is that the granite magma moving upward enveloped two small masses of Marcy anorthosite and tore them into small fragments, which became somewhat scattered and arranged parallel to distinct magmatic currents, which worked its way up nearly vertically, as shown by the high angle of dip of the flow-structure foliation.

In the Schroon Lake quadrangle several inclusions of Whiteface anorthosite bear exactly the same relation to the inclosing syenite-granite series as neighboring inclusions of Grenville, and it seems clear that the upward moving syenite-granite magma enveloped masses of both of these rock types in exactly the same manner.

A very fine display of many inclusions of fragments of Whiteface anorthosite of all sizes occurs in typical granite on Cobble Hill, 1 mile due south of Bailey Pond, in the Schroon Lake quadrangle. A wide zone fully one-fourth of a mile long in the granite contains the inclusions, most of which are arranged parallel to the foliation of the granite (see figure 2).

Inclusions of Whiteface anorthosite in the syenite-granite series were also observed by me in a number of places in the Lake Placid quadrangle. A few will be described. Ledges of syenite by the river one-fourth of a mile east of High Fall contain inclusions of the Whiteface rock arranged parallel to the foliation of the syenite. Similar inclusions occur in syenite by the river one-half of a mile southwest of The Flume and also on top of the hill in the area of mixed gneisses 2¼ miles north-northeast of Keene. An 8-foot boulder of syenite, in the bed of the river about a mile northeast of High Fall, contains several very distinct inclusions of White-

face anorthosite whose borders were fused by the enveloping magma. A big ledge of typical syenite, 1½ miles west of East Kilns, contains many inclusions of Whiteface anorthosite which are bunches, lenses, or bands from 2 or 3 inches to several yards long. Their borders are not always sharp against the syenite. A small body of Whiteface anorthosite 1 mile north of Middle Kilns is really a distinct inclusion in the granite. The same is true of the small body of Grenville-anorthosite mixed rocks a few rods east of Silver Lake at the map edge.

In the Long Lake quadrangle the broad tongue of syenite, already referred to as cutting almost through the border facies of the anorthosite, contains five mappable inclusions of the border facies. From 5 to 7 miles southwest of these the map shows three small masses of Marcy anorthosite, one with sharp contacts against the inclosing syenite, according to Cushing. These are reasonably to be interpreted as inclusions.

The two small mappable bodies of border anorthosite in the Elizabethtown quadrangle, already referred to as occurring in the syenite 1 and 2 miles, respectively, from the main body of anorthosite, are also quite certainly inclusions.

AREAS OF SYENITE SURROUNDED BY ANORTHOSITE

In some places small isolated masses of syenite are completely surrounded by anorthosite. Several such are represented on my Lake Placid geologic map—two of them near Keene, one a mile west of Upper Jay, and another 2 miles southwest of East Kilns. The largest area is only one-half of a mile long, and all are surrounded by the Whiteface type of anorthosite. Kemp's Elizabethtown map shows three such areas—one at the top of Giant Mountain, another a mile north of Chapel Pond, and a third, over a mile across, a few miles west of Elizabethtown. These are all surrounded by Marcy anorthosite except the third, whose eastern side comes against basic border anorthosite. Cushing's Long Lake map shows two small masses of syenite (not including the narrow dikes) surrounded by the basic border anorthosite within a mile of its outer margin. Neither my Schroon Lake map nor Doctor Ogilvie's Paradox Lake map shows a single mass of syenite or granite within the anorthosite.

The few small areas of syenite above mentioned are the only ones represented as completely surrounded by anorthosite on any of the detailed geologic maps. Of these the only ones within Marcy anorthosite are in the Elizabethtown quadrangle. It is therefore a striking fact that such syenite areas are almost entirely absent from the great area of Marcy anorthosite. The significance of this fact is considered beyond, under another caption of this paper.

According to Bowen's hypothesis, these isolated masses of syenite might be regarded as remnants of a former cover of syenite over the anorthosite. But, although positive proof for their intrusive character is, so far as I know, lacking, it is much more reasonable to interpret them as intrusive into the anorthosite. The field relations are in most cases clear enough to make it certain that these syenite masses are rather sharply separated from the anorthosite, which would not be the case if they were differentiates of the same intruded magma.

RELATION OF THE SYENITE-GRANITE SERIES TO CHILLED BORDER OF THE ANORTHOSITE

For the Long Lake quadrangle Cushing[38] says: "The field evidence seems clear that the anorthosite had solidified, with a chilled border, and had then been attacked from the side by a mass of molten syenite, which in places cut deeply into it." With this statement I am in agreement; but I would go further in saying that both granite and syenite of the syenite-granite series have, in certain other districts like the Lake Placid and Schroon Lake quadrangles, not only cut deeply into, but also they have either largely cut out or more or less assimilated, the border facies of the anorthosite. Thus in the Schroon Lake quadrangle only mere remnants of the original wide border facies are left.

Cushing further maintains that the chilled border is fatal to Bowen's conception that molten overlying syenite may have been faulted down against solid anorthosite, so that it could have laterally attacked the anorthosite, thus accounting for the intrusive features, including the syenite dikes. From the detailed field evidence above presented, under the caption "The gabbroid chilled border facies and its significance," it is very certain that the chilled border grades directly into the typical anorthosite, and that there is not the slightest reason to think that the syenite or granite ever developed between the chilled border and the typical anorthosite. Two seeming exceptions should be mentioned. One is the broad belt of syenite which separates the Whiteface type from the Marcy type of anorthosite north of Lake Placid, but, as shown below, it certainly was intruded into this position. The other is a nearly circular area over a mile in diameter a few miles north of Elizabethtown, but the very shape of this mass strongly points to an intrusive origin rather than to its origin as a differentiate *in situ*. Even if we assume, what has not been found in the field, that some such syenite or granite exists as a rock intermediate between the chilled border and the typical anorthosite, it is

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[38] H. P. Cushing: Jour. Geol., vol. 25, 1917, p. 507.

most unreasonable to suppose that the chilled border would in some places grade first into the syenite or granite and then into the anorthosite. Either one of these might be the case, but not both.

Bowen suggests that the syenite-granite may have developed between the chilled border and the Marcy anorthosite and then have been reintruded through the chilled border. But by what stretch of the imagination can we regard the syenite-granite series to have been so largely reintruded that not any of it has been discovered in its supposedly original position? Also when we think of the tremendous volume of syenite-granite immediately around the anorthosite, how can we possibly imagine the reïntrusion of so much magma through the chilled border facies, leaving this latter as a definite fringe about and grading into the anorthosite for so many miles?

SYENITE-GRANITE BODIES OF THE LAKE PLACID AND AUSABLE QUADRANGLES ARE NOT DIRECT DIFFERENTIATES OF ANORTHOSITE

In discussing the distribution of anorthosite and syenite, Cushing[39] says: "The continuity of the main mass (anorthosite) is interrupted by two considerable inlying bodies of other rock (chiefly syenite), one in the Lake Placid region and the other near Keene. . . . Both of these inliers are entirely surrounded by anorthosite and lie well within the mass." These relationships were, no doubt, suggested by the highly generalized State geologic map. He suggests that the anorthosite body, while cooling, may have developed a syenite cover, and that the two so-called inliers just mentioned may be remnants of that cover which have not been removed by erosion. The field facts, as I interpret them, are fatal to this view.

In the first place, the Lake Placid mass referred to is not an "inlier" (or, I would say, "outlier") at all. It is a great body of syenite, with locally developed granite facies, varying in width from 1 to 6 miles and extending into the anorthosite area for 13 miles across the Lake Placid quadrangle, and thence for an unknown distance into the Mount Marcy quadrangle. I have definitely traced this mass right into the extensively developed syenite-granite series of the Lake Placid and Saranac quadrangles, so that there can be no doubt about its being an offshoot from the great syenite-granite body. The syenite mass north of Keene extends eastward into the Ausable quadrangle, and there very likely connects with the broad tongue of the syenite-granite series which reaches southward for a number of miles into that quadrangle (see State map). Whether the Keene syenite area actually connects with this broad tongue is not

[39] H. P. Cushing: Jour. Geol., vol. 25, 1917, p. 502.

known because of lack of detailed field-work. In any case, if there is no direct surface connection, the space between must be narrow.

In the second place, the syenite of these bodies grades into granitic syenite and even into granite, and is in every way exactly like the usual syenite throughout the Adirondack region.

In the third place, I have proved that the Lake Placid syenite-granite mass is intrusive into both the Whiteface and Marcy types of anorthosite, as shown by the dikes, inclusions of anorthosite in the syenite, and the irruptive contacts (see above). There is considerable evidence of somewhat finer grained syenite and granite due to border chilling near the contacts with the older rocks. The distribution of this syenite-granite mass with respect to the surrounding rocks also strongly indicates its intrusive character. It is also very distinctly intrusive into Grenville, as proved both by inclusions and irruptive contacts. In short, the evidence that this body of syenite-granite is really intrusive into and distinctly later than the anorthosite is fully as strong as Cushing's evidence that the syenite of the Long Lake quadrangle is distinctly younger than the anorthosite there.

In the fourth place, as already shown, the chilled border facies of anorthosite certainly developed as a marginal mass lying directly against and grading into the typical Marcy anorthosite. This is clearly true of the border facies (Whiteface anorthosite) in the Lake Placid quadrangle. There is no positive evidence that syenite ever developed as a rock intermediate in position and character between the border facies and the Marcy anorthosite of the quadrangle. A seeming exception is the broad belt between Marcy and Whiteface anorthosite north of Lake Placid; but the facts that this is only a part of the clearly intrusive body both to the north and the south, and that transition rocks are absent, make its intrusive character certain. The narrow belt of transition rock between the syenite and anorthosite on the Sentinel Range is much more plausibly explained as due to assimilative attack on the anorthosite by distinctly later syenite magma (see discussion of "Keene gneiss" below) rather than differentiation *in situ*.

In the fifth place, the foliation of this Lake Placid syenite-granite mass is usually distinct and, as I have elsewhere shown,[40] this is a magmatic flow-structure foliation. The dips are usually high, indicating a notable upward movement of the magma, such as would scarcely be expected to have taken place with a magma developed by differentiation *in situ* between the border facies of the anorthosite and the Marcy anorthosite.

[40] W. J. Miller: Jour. Geol., vol. 24, 1916, pp. 600-612.

Anorthosite and Syenite-granite transition Rocks (Keene Gneiss)

GENERAL STATEMENTS

One of the most interesting rock types of the region is locally developed as belts or irregular bodies along portions of the borders between the anorthosite and the syenite-granite series. Both the Marcy and Whiteface types of anorthosite show such border rocks. There is very strong evidence, based on field-work and a study of thin sections, that this is really a transition rock between anorthosite and syenite or granite due to actual digestion or assimilation of anorthosite by the invading syenite-granite magma along portions of its borders. It is here proposed that this rock be called "Keene gneiss," because a fine exposure of the typical fresh rock occurs by the road just north of the village of Keene, in the Lake Placid quadrangle. In view of the fact that many geologists maintain that there are no definitely proved cases of magmatic assimilation, on considerable scales at least, the evidence furnished by these rocks, especially in the Lake Placid and Schroon Lake quadrangles, has been very carefully considered by me, and I am convinced that actual assimilation has taken place. In other words, the Keene gneiss is quite certainly a good example of hybrid rocks, to use the term suggested by Harker, who maintains that such rocks may be produced either by the mixing of two distinct magma or by the assimilation of solid rock by a magma. Fifteen areas of mostly Keene gneiss are represented on my Lake Placid map. Several areas containing considerable developments of Keene gneiss I have also found in the Schroon Lake quadrangle, one of these occupying about 6 square miles and another about 3 square miles. Others probably exist, but were not located owing to scarcity of outcrops or roughness of country in some places.

Cushing has described rocks, which I would put in the same category with the Keene gneiss, from two localities on the western side of the great anorthosite area. Kemp has described certain peculiar types of gabbro, probably also to be classed as Keene gneiss, as occurring in the Elizabethtown quadrangle. Cushing suggests that these rocks in his districts are magmatic assimilation products, but Kemp says nothing regarding the origin of the peculiar types of gabbro in his district. So far as I know, these are the only rocks of the sort regarding which even brief published statements have been made. Obviously, there is great need of more data regarding such rocks, because the problem of their origin and relations to other rocks has a very important bearing on the whole problem of the anorthosite. Since I have observed these rocks, often with the exhibition

of significant relationships, I shall enter somewhat into the details of their description.

The typical Keene gneiss presents a different appearance from any of the other Adirondack rocks. In the Lake Placid and Schroon Lake quadrangles the typical rock is medium grained, gneissoid, notably granulated, and looks much like a rather basic facies of the syenite except for scattering phenocrysts of bluish gray labradorites up to an inch long. These phenocrysts, which are rounded and usually elongated parallel to the foliation of the rock, doubtless represent cores of crystals which survived the process of granulation. Locally the phenocrysts are absent or sparingly present, and ledges of such rock are difficult to distinguish from a basic phase of syenite. Under the microscope, however, the distinction may generally be made. The fresh rock is greenish gray and it weathers brown.

The mineralogical composition of selected samples of various phases of the rock from the Lake Placid quadrangle are shown in the table on the opposite page.

Labradorite and andesine are always present and oligocene usually. Microperthite occurs in most specimens in varying amounts up to 30 per cent, and orthoclase in most specimens in varying amounts to over 50 per cent. A little quartz is generally present. All the thin sections examined show greenish-gray monoclinic pyroxene; sometimes diallage. A little green hornblende nearly always occurs up to 14 per cent. Garnet varies from none to 12 per cent. Ilmenite or magnetite up to a few per cent never fails. Apatite and pyrite nearly always occur in small amounts. In his recent paper, Bowen states that he has observed, in the transition rocks from anorthosite to syenite, inclusions of potash feldspar, which are small patches, uniformly oriented, and in some cases surrounded by areas of plagioclase differing from the crystal as a whole. A few slight suggestions of this sort were noted by the writer, but certainly this is not a characteristic feature of the Keene gneiss thin sections examined.

SOME OCCURRENCES IN THE LAKE PLACID QUADRANGLE

Occurrence near Keene village.—The type locality of the Keene gneiss is a ledge by the side of the State road at the northern end of the village of Keene, where an excellent opportunity is afforded for the study of the rock and its relations to both anorthosite and syenite. All three of the rocks show as unweathered material in this one ledge, which has recently been blasted open. The anorthosite, which occurs in minor amount, is the typical Marcy facies, consisting mostly of dark bluish gray labradorite up to an inch across, embedded in some granulated labradorite, and asso-

Slide number	Field number	Plagioclase	Microperthite	Orthoclase	Quartz	Monoclinic pyroxene	Diallage	Hornblende	Ilmenite or magnetite	Garnet	Apatite	Zircon	Pyrite	Titanite	Calcite (secondary)
3	4f8	Ol.–Lab. 80	10	..	4	..	3	1	½	little	1	little	little	....	....
10	7f7a	Ol.–Lab. 28	25	20	6½	6	..	...	2	12	¼	¼	....	....	....
11	14g4	An.–Lab. 66	..	20	2	4	..	8	..	....	little	little	....	....	....
12	14b4	Ol.–An. 48	20	..	9	5	..	14	1	....	little	½	....	little	2
41	16j7	An.–Lab. 30	..	51	5	3	..	5	½	5	½	....	little	....	....
42	1k10a	An.–Lab. 70	20	..	1	3	2	2	1	½	¼	....	¼	....	....
45	1k10b	Ol.–Lab. 40	32	10	...	2	8	6½	1	....	½	....	little	....	....

ciated with 10 to 15 per cent ferro-magnesian minerals. The syenite is quite normal in every respect except that it is a little finer grained than usual. A thin section shows the following percentages of minerals: Microperthite, 64; orthoclase, 5; oligoclase, 20; quartz, 6; hornblende, 2½, and other very minor constituents.

Most of the rock of the ledge, however, is clearly an assimilation product of syenite and anorthosite. This rock (Keene gneiss) exhibits at least three distinguishable facies. One is highly gneissoid, with elongate cores of labradorite crystals as phenocrysts, up to an inch long, arranged parallel to a distinct foliation. Its mineral content is given as number 42 of the above table. A second facies is only faintly gneissoid, with labradorite phenocrysts only roughly parallel to the foliation. Its composition is given as number 45 of the table. The presence of orthoclase and a greater amount of microperthite makes this rock more syenitic than the first facies. In the two facies just described the phenocrysts of labradorite not only finely exhibit polysynthetic twinning, but they are also perfectly and conspicuously twinned according to the albite law, thus giving the freshly broken surface a striking appearance. Both of these facies are notably granulated, and the rounded phenocrysts are the uncrushed portions of what were once still larger crystals. A third facies, in minor quantity, is non-foliated and contains no phenocrysts, but it does contain a few rounded red garnets up to an inch across. This third facies is the most syenitic of the three.

All three facies just described grade into each other and they are quite certainly only phases of a single cooling magma. Also it is important to note that the Keene gneiss is not sharply separated from the true syenite on one side and the true anorthosite on the other, but rather by narrow transition zones. All three facies of this Keene gneiss are certainly intermediate in composition between the syenite and anorthosite, the first one described having decided anorthosite affinities, the third having decided syenite affinities, and the second being no more syenitic than anorthositic. The conclusion, therefore, based on the field relations and composition of the rocks, is that we have here a true magmatic assimilation product, the invading syenite magma having actually incorporated and digested more or less of the anorthosite material.

The close juxtaposition of the syenite and Keene gneiss may be reasonably explained by considering the syenite to have been an intrusive offshoot from the near-by large body of syenite into previously formed and cooling, or possibly solidified, Keene gneiss magma, the temperature then having been high enough only to permit fusion along a narrow border

zone between the intruded and intruding masses, thus accounting for the narrow transition zone between the two in the ledge.

The foliation of this Keene gneiss is quite certainly an original structure due to magmatic flowage under moderate pressure, and accordingly the marked differences in degree of foliation within this one outcrop are regarded as the result of differential magmatic flowage.

It is clearly evident that the typical Keene gneiss just described is of very local origin. Evidence of the local origin of other Keene gneiss is presented below. The larger bodies of Keene gneiss are in every way like these smaller ones, and there is good reason for believing, therefore, that all the Keene gneiss, even where present as considerable bodies, is of rather local origin due to assimilative attack of molten syenite or granite on anorthosite. This is, of course, directly opposed to Bowen's hypothesis, which regards the transition rock (Keene gneiss) as having formed by differentiation *in situ* between syenite and anorthosite.

Area near Upper Jay.—In the area of over one-half of a square mile, just east of Upper Jay, there are many good exposures, certain of them of particular interest because they throw important light on the origin and relations of the Keene gneiss. Near the top of the hill, at the northeastern border of the area, syenite and Whiteface anorthosite in big exposures are separated by a zone, a few feet wide, of basic syenite-like rock with scattering bluish gray labradorites. This is certainly a transition zone of typical Keene gneiss produced by the assimilation of Whiteface anorthosite by syenite magma. On the little hill, just south of the center of the area, several outcrops of typical Keene gneiss contain bands or lenslike inclusions of Whiteface anorthosite, Keene gneiss magma, moving from a lower level where it was formed, evidently having penetrated or caught up small masses of unchanged Whiteface anorthosite at a higher level. The Keene gneiss here contains many tiny red garnets, and the labradorites are very conspicuous on the weathered surfaces.

Sentinel Range area.—This long narrow area extends east-west across the middle of the Sentinel Range. It is about 4 miles long and nowhere over one-fourth of a mile wide. It is all in a rough, densely wooded country, but a good many outcrops make the mapping fairly satisfactory. Perhaps the most instructive ledges are on the little hill 1 mile northeast of Malcom Pond. The top of this hill is quite typical Marcy anorthosite. On the southern side the rocks are variable, being mostly fine to medium grained, gneissoid, and of gabbroid appearance, with some closely involved basic syenite-like rock containing a few small, scattering labradorite phenocrysts. Near the top of the hill, on the west side, the rock is coarser

grained, with few dark minerals, and this appears to be quite typical Keene gneiss. All the types mentioned grade into each other.

On the hillside, one-half of a mile southeast of the hill just mentioned, there are outcrops of a moderately coarse grained, rather gabbroid rock with some labradorite phenocrysts. Its mineralogical composition, number 3 of the above table, shows that it is Keene gneiss with strong anorthosite affinities. There are still other good exposures in this Sentinel Range area.

Sunrise Notch area.—This is the largest area of Keene gneiss in the quadrangle (see figure 1). It is about 3½ miles long and from one-half to two-thirds of a mile wide. Most of the outcrops are quite typical Keene gneiss, though usually not strongly foliated. The rock is generally medium grained, with scattering labradorite phenocrysts. It weathers brown.

A locality of special interest is a cliff on the southern border of the area, three-fourths of a mile east of the summit of Sunrise Notch. Most of this rock is very gneissoid and only moderately gabbroid Whiteface anorthosite, a little finer grained than usual. Within this rock there is a wide band of fine grained, very gneissoid, gray rock with a reddish tinge due to numerous tiny garnets. The composition of this local band, number 10 of the above table, causes it to be classed as Keene gneiss with strong syenite affinities. Its contact against the anorthosite is not very sharp. Evidently a dike or tongue of the Keene gneiss magma here intruded the Whiteface anorthosite near its border, and the temperature was high enough to cause fusion of the anorthosite walls of the dike or tongue.

Area west of East Kilns.—This area, between 1 and 2 miles west of East Kilns, shows certain interesting and important features. Much of the rock has strong syenite affinities because of the high content of orthoclase.

Near the middle of the northern boundary syenite contains inclusions of Whiteface anorthosite as bunches, lenses, and bands from two or three inches to several yards long, the boundaries of the inclusions usually not being very sharp. Evidently very little assimilation of anorthosite took place here.

Along the northwestern side several ledges are very gabbroid in appearance, in some places very gneissoid and in others not. Locally there is very intimately associated syenite and Whiteface anorthosite. Apparently these ledges show the effects of partial digestion or assimilation of anorthosite by the syenite magma.

Along the main brook, for one-fourth of a mile after it enters the area, there are good exposures of homogeneous, scarcely gneissoid Keene gneiss, with phenocrysts not as large as usual. This rock, whose composition is given as number 41 of the above table, has strong syenite affinities because of its high orthoclase content. In this portion of the area syenite magma quite certainly completely assimilated more or less anorthosite.

At one place on the little hill, in the eastern part of the area, fairly coarse granite is intimately associated with gabbroid Whiteface anorthosite with local development of what appears to be an assimilation product containing some quartz.

SOME OCCURRENCES IN THE SCHROON LAKE QUADRANGLE

An outcrop on the southern brow of Cobble Hill, 1 mile due south of Bailey Pond, is very significant because of the light it throws on the local origin of the Keene gneiss. The accompanying sketch (figure 2) shows the relationships. This Keene gneiss is distinctly granitic in appearance except for the many labradorite crystals, mostly about an inch long, which stand out as distinct phenocrysts more or less parallel to the crude foliation of the otherwise medium grained rock. Within this rock are inclusions of Whiteface anorthosite, which contains some large labradorites and also scattering femic minerals up to two inches long, more or less lenslike and parallel to a distinct foliation. Contacts between the inclusions and the Keene gneiss are not very sharp. Immediately above this Keene gneiss, but not in very sharp contact with it, is a very gneissoid granitic gneiss which contains many garnets. This granitic gneiss grades upward into typical, medium grained, only moderately foliated granite without garnets. A similar typical granite lies against the Keene gneiss at the bottom, but the contact there is quite sharp. My interpretation is that the upward moving granite magma more or less assimilated some Marcy anorthosite at a considerable depth, and that this molten mass (Keene gneiss magma) having risen still higher caught up and only fused the borders of fragments of Whiteface anorthosite. The origin of the garnetiferous granite is not so certain, though it may represent a mass of granite with a small quantity of anorthosite very thoroughly digested.

Interesting exposures occur in a small area near the southeastern base of Severance Hill. The rocks are mostly peculiar basic-looking syenitic gneisses, well foliated, medium to fine grained, garnetiferous, and greenish gray where fresh, but they are quite variable with considerable local development of quartz. They differ from the typical Keene gneiss in not having the large bluish labradorites. I have not yet had opportunity to study thin sections of this rock. One large exposure shows numerous

small inclusions of Whiteface anorthosite whose borders against the syenitic looking rock are by no means sharp. Apparently quartz syenite or granite magma rising through anorthosite assimilated some of it and then, rising still higher, caught up numerous small fragments which were not completely digested.

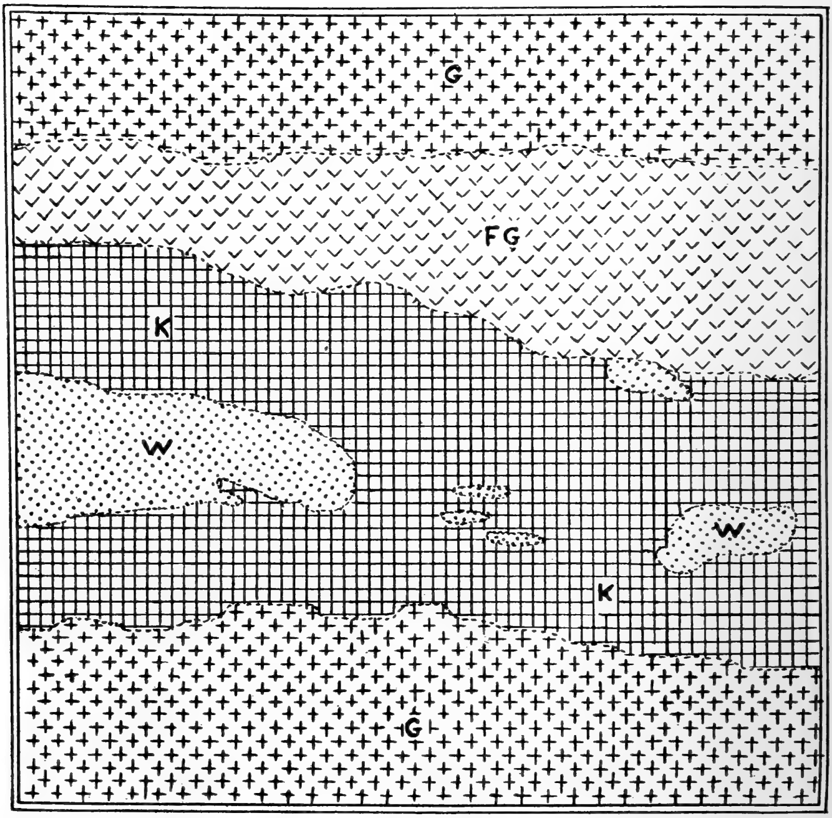

Figure 2.—***Relations of Keene Gneiss to other Rocks on the southern Brow of Cobble Hill, in the Schroon Lake Quadrangle***

Dimensions, 30 by 30 feet. *K* = Keene gneiss, *W* = Whiteface anorthosite, *FG* = highly foliated granite with garnets, and *G* = typical moderately foliated granite. Not very sharp contacts between *K* and *W* and between *K* and *FG*. *G* grades perfectly into *FG*.

By the trail, 2 miles northeast of Bailey Pond, there is a large outcrop of peculiar variable rock. There are some small patches of Whiteface anorthosite embedded, but most of the rock looks like granite or granitic syenite with scattering bluish gray labradorites up to an inch long. This latter looks very much like the Cobble Hill rock above described, except

for fewer labradorites, and I believe it to be Keene gneiss with the same history as that on Cobble Hill.

On much larger scales I have mapped two areas of Keene gneiss, one occupying about 6 square miles and the other nearly 3 square miles. Before the intrusion of a large gabbro stock the two areas were probably connected with a total length of nearly 7 miles. These bodies of Keene gneiss lie against typical Marcy anorthosite, the border facies of anorthosite here having been very largely assimilated by granite or syenite-granite magma. Throughout the larger area especially there are a good many small masses of Whiteface anorthosite, a few of sufficient size to be mapped, and some outcrops of fairly good granite or granitic syenite, thus showing that the assimilation was not everywhere thorough. The main bodies of the rock are quite typical Keene gneiss. The inclusions of anorthosite indicate the true intrusive character of the Keene gneiss.

Enough examples have been described to prove that Keene gneiss has developed on small and large scales by assimilation of anorthosite by granite or granitic syenite magma instead of by syenite magma, as is usually the case in the other Adirondack districts thus far studied. If we adopt Bowen's hypothesis, this Keene gneiss must be regarded as having developed by differentiation *in situ* between an overlying sheet of syenite-granite and underlying anorthosite. If one admits, as I do not, that syenite usually may have developed by differentiation *in situ* close on the Marcy anorthosite, how can one imagine, in other places like the Schroon Lake quadrangle, a similar development of granite close on the anorthosite? It might be argued that the granite magma formed at a higher level and was then forced downward. But, if so, it must have been forced downward through the still lower syenitic material. Not only is the field evidence against this view, as already pointed out, but even if we grant it, we are still forced to the conclusion, by the obvious field facts, that the granite magma produced the transition rock (Keene gneiss) by assimilation of more or less anorthosite, and that the Keene gneiss was not formed as a differentiate *in situ* between an overlying sheet of syenite-granite magma and underlying anorthosite.

KEENE GNEISS OF OTHER ADIRONDACK REGIONS

In Cushing's report on the geology of the Long Lake quadrangle, he describes a basic phase of the syenite which grades into a rather fine grained, even granular, gneissoid rock with few feldspar phenocrysts and dark minerals often equaling or exceeding the feldspar in quantity. Some of the feldspar is microperthite and some oligoclase-andesine.

"The most of the basic syenite, and all of the more gabbroic of it, is in close association with the anorthosite border. . . . Now the syenite is unquestionably younger than the anorthosite, and the observed relations seem to point to the conclusion that the change (in the syenite) is due to actual digestion, by the molten syenite, of material from the (anorthosite) gabbro." [41]

The Keene gneiss of the Lake Placid region differs in being coarser grained, distinctly porphyritic, and not so rich in dark minerals; but both Cushing's basic syenite and the Keene gneiss are intermediate in position and composition between the anorthosite and the syenite-granite in their respective regions, and I believe Cushing's suggested explanation is the correct one.

Another rock, earlier described by Cushing[42] from a railroad cut nearly 5 miles north of Tupper Lake Junction, is regarded by him as intermediate between the syenite and anorthosite. Judging by the description, this rock is in most ways similar to the typical Keene gneiss, except that the phenocrysts of labradorite are not so large.

In Kemp's report on the geology of the Elizabethtown-Port Henry quadrangle,[43] he describes two peculiar types of gabbro with distinct anorthosite affinities. One of these, called the Woolen Mill type, "is dark, gneissoid, and of moderate coarseness of grain. It resembles a rather basic member of the syenite series, but has occasional blue labradorite phenocrysts which ally it with the anorthosites." The minerals contained are green pyroxene, plagioclase, orthoclase, quartz, garnet, pyrrhotite, apatite, and sometimes biotite and hornblende. Kemp states that this sort of rock also occurs along the southern border of Blueberry Mountain. Having seen this rock in the field, I quite confidently class it with the Keene gneiss. He says that the rock called the Split Rock Falls type "is suggestive of the anorthosite in that labradorite is the chief feldspar present, but the dark silicates are more abundant, and when crushed and sheared the rock yields a decidedly foliated gneiss. It then becomes a hard dense rock, exceedingly tough. Nevertheless, large phenocrysts of labradorite are not uncommon." Both of these types are demonstrably younger than the anorthosite, the first showing an irruptive contact against the anorthosite and the second containing inclusions of anorthosite. The fact that these rocks are intrusive into the anorthosite harmonizes with my own observations (see above) on the Keene gneiss—that is to say, in such cases the Keene gneiss magma developed as an assimilation product at a lower level and was then forced upward in some places

[41] H. P. Cushing: N. Y. State Mus. Bull. 115, 1907, p. 479.
[42] H. P. Cushing: N. Y. State Mus. Rept. 54, vol. 1, 1902, pp. *r*43 and *r*68.
[43] J. F. Kemp: N. Y. State Mus. Bull. 138, 1910, pp. 37-40.

to include fragments of the anorthosite and in other places to yield irruptive contacts against the anorthosite at higher levels.

SIGNIFICANCE OF THE DISTRIBUTON OF THE KEENE GNEISS

That the Keene gneiss is actually an assimilation rock, the product of fusion and digestion of anorthosite by syenite or granite magma, is regarded proved by the evidence above presented. It can not be a direct differentiate of either the syenite-granite series or the anorthosite, because it never occurs except on the border or close to the contact between the syenite or granite and the anorthosite. But such rock is not universally present. For instance, the long boundaries between the Whiteface anorthosite and granite of Mount Whiteface and between the Whiteface anorthosite and syenite from the southern side of Mount Whiteface to west of Knapp Hill were crossed by me at a good many places without noting any rock like the Keene gneiss. Some other places also have no Keene gneiss as a border rock. It is probable that some masses of Keene gneiss may have been overlooked in the rough, densely wooded country, and that some may lie under cover of Pleistocene deposits; but, in view of the detailed surveys of the Lake Placid and Schroon Lake quadrangles, it is certain that any such masses must be relatively small in those districts.

By way of contrast with the conspicuous development of Keene gneiss, the syenite-granite series about the great anorthosite body shows little evidence of having assimilated Grenville rocks. The Keene gneiss, particularly in the Lake Placid quadrangle, forms belts between the syenite-granite series and the border (Whiteface) facies of the anorthosite as well as between the syenite-granite and Marcy anorthosite. In both cases the Keene gneiss exhibits essentially the same characteristics. Not everywhere does the Keene gneiss exist as definite zones or belts with syenite or granite directly adjacent on one side and anorthosite on the other.

How are these differences in distribution of the Keene gneiss to be accounted for? Also, why do the borders between the Grenville and syenite-granite, as well as the Grenville and syenite-granite mixed gneisses, show little or no evidence of magmatic assimilation? I believe the answer to these questions may be found in the temperature relations of the rocks at the time of the intrusion of the syenite-granite series. If we consider that the great mass of anorthosite was still at a relatively high temperature, though not necessarily molten, it would have been only necessary for the syenite-granite magma to have raised the temperature of the borders of the anorthosite comparatively little to have effected actual assimilation.

The tongues of syenite cutting Whiteface anorthosite on Wilmington Mountain, and the tongues of granite cutting similar anorthosite on the side of Mount Whiteface (see figure 1), furnish important evidence in support of this view, because these tongues or dikes, instead of being in sharp contact with the anorthosite, show very narrow transition zones due to slight fusion of the anorthosite. Now it does not seem probable that even small amounts of comparatively cold anorthosite could have been fused and assimilated by such small masses of intrusive magma, but with the anorthosite at a high temperature, though not really molten, the borders might very conceivably have been fused. Thus, if we make the very simple and plausible assumption that the anorthosite was still very hot when the syenite-granite magma was intruded, or, in other words, if this latter magma was forced up comparatively soon after the development of the anorthosite, the usual strong objection to magmatic assimilation, namely, that a magma does not possess a sufficiently high temperature to raise relatively cold country rock to the point of fusion, is distinctly obviated.

Where no Keene gneiss occurs along the borders, it may be plausibly conceived that either the anorthosite or the syenite-granite, or both, may not have been hot enough to permit assimilation. In this connection, it should be noted that the prominent mass of syenite-granite which projects for many miles into the anorthosite of the Lake Placid quadrangle (see above) shows little or no development of Keene gneiss along its borders except well within the quadrangle, where it is reasonable to believe that the anorthosite was hotter, due to greater thickness and slower cooling of the laccolithic body there. In both the Schroon Lake and Long Lake quadrangles, however, considerable developments of Keene gneiss took place along or close to the outer margin of the great body of anorthosite, probably because on the south and west sides the anorthosite of the laccolith was notably thicker, and hence kept hot longer (see figure 3).

The presence of Keene gneiss in one place and its absence from the same border near by may in some cases have been the result of unequal upward intrusion of Keene gneiss magma which originated at a lower level.

The failure to find any considerable assimilation of Grenville either along its border with, or where involved with, the syenite-granite series may be explained on the basis of a temperature of the Grenville too low to have permitted any more than comparatively slight assimilation by the invading syenite-granite magma. It should be borne in mind, however, as pointed out in a recent paper by the writer,[44] that local assimilation was not uncommon in certain parts of the Adirondack region.

[44] W. J. Miller: Bull. Geol. Soc. Am., vol. 25, 1914, pp. 254-260.

How shall be explained the fact that typical Keene gneiss in some places forms belts between syenite or granite and Marcy anorthosite and in other places between syenite or granite and the border (Whiteface) facies of the anorthosite, the Keene gneiss exhibiting almost exactly the same characteristics in each case? If we adopt Bowen's hypothesis, we are obliged to imagine the development of two sheetlike masses of Keene gneiss, one just above the syenite-granite and the other just below it. Is it not most unlikely that two masses, formed under such different conditions, would be almost exactly the same? This difficulty is obviated by regarding the Keene gneiss as an assimilation product. In my experience, particularly in the Lake Placid quadrangle, Keene gneiss seldom formed except well within the outer margin of the great body of anorthosite where the temperature was still relatively high. The field relations strongly indicate that assimilation of Whiteface anorthosite took place only where that rock was well within the outer margin—that is to say, where such Whiteface anorthosite was near its change to Marcy anorthosite.

In the mixed rock areas, where anorthosite has been cut to pieces by intrusions of syenite, the few contacts observed are not very sharp. Apparently in these areas either the syenite magma or the anorthosite, or both, were not hot enough, or the syenite was not in sufficient bulk to effect more than slight fusion of the borders of the invaded anorthosite.

Another important fact is that in the field the Keene gneiss by no means universally forms a narrow zone or belt with syenite-granite directly adjacent on one side and anorthosite on the other. A fine case in point is the eastern part of the Sunrise Notch area (see figure 1), where Keene gneiss for 1½ miles lies between granitic syenite on one side and syenite on the other. A different case is the Oak Ridge area northeast of Keene. This is bordered on the south by Whiteface anorthosite and on the north by Grenville, Marcy anorthosite, and syenite. How can areas of this sort possibly be explained by Bowen's hypothesis, which assumes that the anorthosite was never a real magma, but that it was formed by sinking of plagioclase crystals with the development of a transition rock (Keene gneiss) occupying a position distinctly intermediate between the syenite-granite and anorthosite? Is it not much more in harmony with the field relations to conceive that Keene gneiss magma was produced by assimilation at a lower level and then rose to invade previously formed Grenville and anorthosite, or moved upward, flanked on either side by syenite or granite? Also, are not elliptical areas like those just east of Upper Jay and 1½ miles west of East Kilns much more satisfactorily accounted for in this manner than by Bowen's hypothesis? Again, do

not the inclusions of anorthosite in the Keene gneiss (see above) strongly support my view that the Keene gneiss, in some places at least, moved upward as a true magma?

Finally, while there are such good reasons for believing that in many cases the Keene gneiss magma formed at lower levels and rose to higher levels in true intrusive fashion, it is also true that in many places, particularly in the Long Lake quadrangle, there appear to be no evident irruptive contacts of Keene gneiss against anorthosite, but rather a gradation. In such cases the assimilation or digestion of anorthosite by syenite or granite magma is conceived to have taken place with little or no movement of the resulting hybrid magma. This seems also to be essentially true of the long, narrow area of Keene gneiss between syenite and Marcy anorthosite across the Sentinel Range, in the Lake Placid quadrangle.

BOWEN'S SUGGESTION OF POSSIBLE ORIGIN OF SOME KEENE GNEISS BY ASSIMILATION

To argue that because there is a transition rock (Keene gneiss) does not prove Bowen's hypothesis of a stratiform arrangement with syenite-granite above and anorthosite below, the transition rock being a differentiate *in situ* between the two. This utterly ignores the possibility of the origin of the Keene gneiss by magmatic assimilation. In his second paper, Bowen emphasizes the point that much of the syenite magma, which he conceives to have been formed just under the upper gabbroid border phase of the great intrusive, could have intruded and partially assimilated the border phase, thus giving rise to some rocks intermediate between syenite and gabbroid anorthosite, such as those described by Cushing. Now, while it is significant that Bowen admits the possible origin of some such rocks by magmatic assimilation, the plain fact is that no syenite ever formed as a rock intermediate between true anorthosite and the gabbroid border phase, as already proved, so Bowen's hypothesis to account for certain rocks intermediate between syenite and gabbroid anorthosite is wholly out of the question.

SIGNIFICANCE OF THE DISTRIBUTION OF FEMIC MINERALS

According to Bowen, a sheetlike arrangement of syenite-granite, anorthosite, and pyroxene or peridotite developed, due to settling of crystals in an original gabbroid magma, the femic minerals having very largely gone to the bottom, except probably from the very uppermost chilled border facies. Thus the syenite should be notably poorer in femic minerals than the anorthosite, and also the transition rock which, according

to Bowen, formed between the syenite and anorthosite should be poorer in femic minerals than the anorthosite. Now, in my experience, just the reverse is true. The average syenite is notably, and the average transition rock (Keene gneiss) is perceptibly, richer in femic minerals than the anorthosite. This is a fact overlooked by Bowen. Why were more femic minerals left in the overlying syenite and transition rock magmas than in the underlying anorthosite, according to his view, when the tendency was for such crystals to go to the bottom? This serious difficulty is entirely obviated if we consider the anorthosite to be a separate instrusive distinctly older than the syenite-granite series.

SIGNIFICANCE OF THE THICKNESS OF THE KEENE GNEISS

The thickness of the Keene gneiss is very significant. It almost always occurs as narrow belts or zones between syenite or granite and anorthosite. A very fine example is the narrow belt forming a transition between syenite and typical Marcy anorthosite across the Sentinel Range of the Lake Placid quadrangle. If we consider its thickness to be approximately represented by the width of the outcrop, it would be but little more than a thousand feet; and this is my view. But, according to Bowen's hypothesis, this Keene gneiss must extend as a layer southward under the syenite, and hence its thickness would be much less; in fact, scarcely more than a few hundred feet. Now, within this short distance the passage from typical quartz syenite into typical Marcy anorthosite takes place. The Marcy anorthosite is certainly at least some thousands of feet thick, several thousand feet in thickness being exposed in single mountains, and so with the syenite. I can not conceive of the development of two rock masses, syenite above and anorthosite below, on such a grand scale by the sinking of plagioclase crystals in a slowly cooling magma under deep-seated conditions, as required by Bowen's hypothesis, without the formation of a notably thick transition rock, fairly comparable in bulk to the overlying syenite and the underlying anorthosite. But this is far from the case as demonstrated by the field relations. As matter of fact, as already pointed out, such a transition rock never formed at all in some places.

General Absence of Grenville and Syenite-granite from the Anorthosite Area

It is a striking fact that both Grenville and syenite-granite are almost, if not entirely, absent from a large part of the area of anorthosite.

Bowen[45] says: "Not only is the anorthosite unbroken by areas of Grenville, especially away from the margins, but it is likewise practically free from protrusions of the syenite." Although this statement needs to be modified, I believe it constitutes the strongest single argument in favor of Bowen's hypothesis. It is not, however, opposed to my conception of the structure and origin of the anorthosite. The statement is by no means true for the northeastern half of the anorthosite area which is covered by the Lake Placid and Ausable quadrangles and the northern portions of the Mount Marcy, Elizabethtown, and Port Henry quadrangles and the western half of the Willsboro quadrangle. There are extensive developments of both Grenville and syenite-granite throughout this northeastern half of the anorthosite area. In the southwestern half of the area, however, the absence of Grenville and syenite or granite is indeed an impressive fact, though it must be remembered that many square miles of this have never been carefully surveyed. The detailed Long Lake, Schroon Lake, Paradox Lake maps and the southern half of the Elizabethtown map show no areas of Grenville or syenite-granite. As I understand it, this is also true of the southern half of the Mount Marcy quadrangle.

According to Bowen:[46]

"If one pictures the syenite and the anorthosite as conventional batholiths, some difficulty is experienced in accounting for the foregoing facts. It is necessary to imagine an early intrusion of a huge plug of anorthosite followed by an intrusion of syenite which took the form of a hollow cylinder circumscribing it and invading it only peripherally. . . . On the other hand, if one pictures the Adirondack complex as essentially a sheetlike mass with syenite overlying anorthosite . . . one would expect to find areas of Grenville roof covering the syenite in places and to find it relatively little disturbed. In the interior and eastern region of maximum uplift one would expect to find the deep-seated anorthosite laid bare and to find it free from areas of the roof."

Also, because of the deep erosion in the region of maximum uplift, one would expect to find the layer of syenite removed.

My view is quite different. As I have repeatedly shown in this paper, it is certain that the anorthosite represents a separate and distinctly older intrusion than the syenite-granite, so that the sheetlike arrangement advocated by Bowen is out of the question. But it is by no means necessary, therefore, to assume that both syenite-granite and anorthosite were batholithic intrusions. I believe the anorthosite represents a laccolith not much greater across than the present area of outcrop, and that its intrusion was soon followed by a very irregular intrusion of the great body of

[45] N. L. Bowen: Jour. Geol., vol. 25, 1917, p. 223.
[46] N. L. Bowen: Jour. Geol., vol. 25, 1917, pp. 223-224.

generally rather highly fluid syenite-granite magma. That the syenite-granite magma was rather highly fluid is proved by its great power to cross-cut, intimately penetrate, break up, and tilt the Grenville strata. Only exceptionally did local portions of this magma invade the Grenville strata in true laccolithic fashion.

Both the anorthosite and the syenite-granite, I believe, intruded a very thick mass of essentially undisturbed Grenville strata, largely or altogether free from orthogneiss. The southwestern half of the anorthosite body, which is so free from masses of Grenville and syenite-granite, I believe represents the greatest bulk of the anorthosite where the laccolithic magma was thickest and reached the highest level. The northeastern half of the anorthosite, as now exposed, I regard as the portion where the magma spread out as a relatively much thinner layer whose surface was at a notably lower level than that of the thicker portion to the southwest (see figure 3). Because of the greater uplift of the southwestern portion the Grenville cover has been almost, if not completely, removed by erosion. But many areas of the Grenville roof remain over the thinner northeastern part where the uplift was much less. Thus we have a simple explanation of the absence of the Grenville from so much of the anorthosite area.

After the solidification of the great body of anorthosite, the syenite-granite magma was batholithically intruded in a rather highly fluid state and tended to avoid penetration of the anorthosite which was much more massive, homogeneous, and resistant than the great mass of surrounding practically undisturbed Grenville strata. This satisfactorily explains not only why syenite-granite masses are scarcer within the anorthosite area than in the Adirondack region in general, but also why syenite-granite masses are almost, or entirely, absent from the southwestern half. I do not believe it necessary to assume that the feeding channel of the laccolith was as small as generally represented in diagrams of laccoliths. May not there have been a wide feeding channel extending northwest by southeast under the main body of the southwestern half of the anorthosite? On this view, the thickest portion of the laccolith developed directly over the wide feeding channel which extended far down, with the result that this portion of the anorthosite intrusive body was very resistant to intrusion by the syenite-granite magma. The northeastern portion of the anorthosite, because notably thinner, was penetrated by considerable masses of the syenite-granite magma, as in the Lake Placid and Ausable quadrangles. Here, again, we have a simple explanation of the field facts.

If we do not accept the hypothesis of stratiform arrangement of the syenite-granite and anorthosite, we are therefore not forced, as Bowen

says, to imagine a batholithic intrusion of the anorthosite followed by a batholithic intrusion of syenite-granite which took the form of a hollow cylinder which invaded the anorthosite only peripherally. This statement by Bowen is opposed by the field facts, since the whole northeastern half of the exposed anorthosite body has been deeply invaded by very considerable masses of syenite-granite.

If we adopt Cushing's view of Grenville resting on older orthogneiss, this latter rock would have made the country rock distinctly more resistant to intrusion by the syenite-granite magma, and hence we should not expect the relative amounts of syenite-granite within the anorthosite area and the region outside of it to be so notably different. So far as I know,

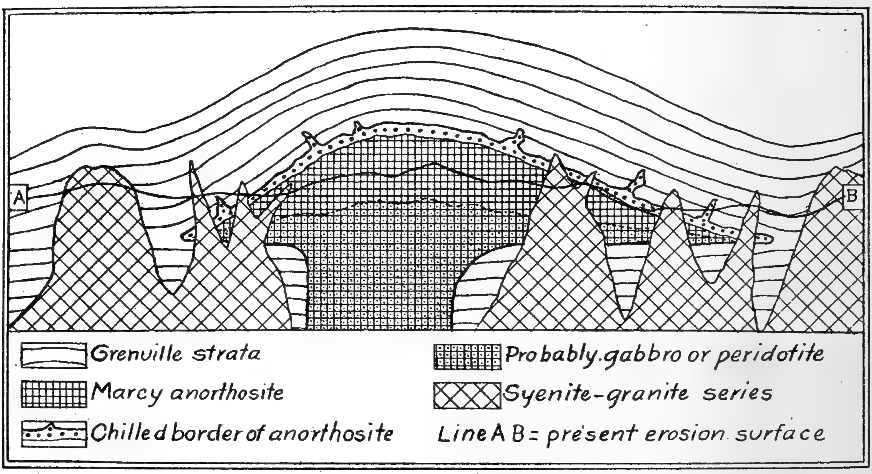

FIGURE 3.—*Highly generalized Northeast-Southwest Structure Section through the Adirondack Anorthosite Body*

Showing the relation of the anorthosite to the Grenville and syenite-granite series

Cushing does not take up the important problem of the general absence of the syenite-granite series from the anorthosite.

Strongly supporting my explanation of the absence of the syenite-granite from the southwestern half of the anorthosite area is the evidence from the distribution of the later gabbro stocks. All the more recent workers in Adirondack geology recognize this gabbro as distinctly younger than the syenite-granite series. It occurs usually in the form of stocks or pipelike forms rarely more than a few miles across. Such stocks are very common and widespread throughout the Adirondack region except the anorthosite area. Like the syenite-granite, this gabbro is singularly absent from the southwestern half of the anorthosite body. The detailed

Elizabethtown, Paradox Lake, Schroon Lake, and Long Lake maps show no gabbro well within the margin of the anorthosite, except a very small mass 2 or 3 miles within the border in the Long Lake quadrangle. So far as I know, none occurs in the southern half of the Mount Marcy quadrangle. On the southern side of the anorthosite area gabbro stocks are present in unusual abundance right up to the very border of the anorthosite, beyond which none are found. In the Schroon Lake and Elizabethtown quadrangles a number of gabbro stocks from 2 to 4 miles long lie right along the border. In the northeastern portion of the anorthosite area, however, small gabbro stocks occur in moderate numbers, as, for example, in the Lake Placid quadrangle.

It is, then, very clear that this later gabbro shows the same sort of distribution with reference to the anorthosite as does the syenite-granite, and I believe the same explanation (see above) applies to both. Evidently the gabbro intrusions were unable to penetrate the thick, very resistant southwestern half of the anorthosite laccolith. Since the gabbro stocks are distinctly intrusive and later than both the anorthosite and the syenite-granite, their absence can not be explained as due to removal by erosion from a large part of the anorthosite area. How would Bowen explain the fact that this later gabbro shows exactly the same remarkable distribution with reference to the anorthosite as does the syenite-granite series? Is the absence of this gabbro from so much of the anorthosite area any less remarkable and explainable in a different way than the absence of the syenite-granite?

Origin of Anorthosite by Differentiation in a Laccolith of Gabbroid Magma

LACCOLITHIC STRUCTURE OF THE ANORTHOSITE

According to Bowen, the anorthosite and the syenite-granite series are both essential parts of a single vast laccolithic body whose diameter is at least as great as that of the whole Adirondack region. To say the least, this would be a tremendous laccolith. The main thesis of my paper has been to show that this hypothesis is untenable in the face of many important field facts.

In his recent paper, Cushing states that he does not object "to the laccolithic conception, but to the conception of a single laccolith occupying the entire region." He argues that the anorthosite is a separate intrusive body distinctly older than the syenite-granite series, but he does not present evidence for the laccolithic structure of the Adirondack anorthosite.

Daly,[47] after considering a number of the better known anorthosite bodies of the world, concludes that all of them, including the Adirondack mass, are best to be regarded as laccoliths.

In this paper I have presented many field facts which best harmonize with the conception of a laccolithic structure of the Adirondack anorthosite. As already shown, it is not at all necessary to assume, as does Bowen, that both the syenite-granite series and the anorthosite were batholithic because they are regarded as distinctly separate intrusions. I believe the anorthosite body (not necessarily anorthosite as such) was intruded essentially laccolithically, while the syenite-granite series was intruded essentially batholithically.

Positive proof for the laccolithic structure of the Adirondack anorthosite can not be won from a study of its relation to the intruded Grenville strata. In the first place, only a very few (usually small) areas of Grenville are known to lie against the borders of the anorthosite, having been cut out so extensively by the syenite-granite series, and these contacts are almost all concealed under Pleistocene deposits. In the second place, such Grenville strata were more or less disturbed again by the later syenite-granite intrusion.

My reason for regarding the anorthosite as essentially a laccolithic body is that many of the important field facts support this conception, while none are opposed to it. Since I have already presented and discussed these facts, I shall not repeat the details here. Among the many facts in harmony with the laccolithic conception are the following: The chilled border facies, which developed as an upper as well as an outer border, resting directly on and against the Marcy anorthosite; failure to find masses (even small inclusions) of Grenville country rock farther within the anorthosite than just below the inner margin of the chilled border, thus indicating the power of the anorthosite to have lifted rather than to have extensively cross-cut or engulfed Grenville; failure of both the syenite-granite series and the gabbro stocks to penetrate the main body of the southwestern half of the anorthosite, and moderate penetration of the northeastern half by the rocks just named, thus very strongly suggesting a laccolith very thick toward the southwest and relatively thin toward the northeast.

PROBABLE ORIGIN OF THE ANORTHOSITE BY SETTLING OF FEMIC CONSTITUENTS

It might be possible to conceive the anorthosite to have been intruded in the form of a laccolithic magma whose composition was practically the

[47] R. A. Daly: Igneous Rocks and Their Origin. 1914, pp. 328-335.

same as that of the present rock, and whose margin, in which femic constituents tended to accumulate, developed as a chilled rather gabbroid border. As already shown in this paper, I see no difficulty in assuming that this anorthosite may actually have been sufficiently molten as such to have been laccolithically intruded, but there is a real difficulty in trying to account for the tendency of the femic constituents to gather in the marginal portion.

My conception is that the anorthosite resulted from the settling of femic constituents in an originally gabbroid magma. This is fundamentally the view expressed by Daly,[48] who, after considering many of the world's best known laccoliths and sills, says: "The anorthosites of the world are best regarded as . . . gravitative differentiates of gabbroid magma" usually in laccoliths. Regarding differentiation of magmas in general by sinking of crystals, Clarke[49] says: "Gravitative adjustment is presumably most effective in slowly cooling magmas, especially when partial crystallization has occurred. The minerals first formed must have time to sink. The rate of cooling, therefore, is a distinct factor in the differentiation of igneous rocks." There is every reason to believe that the great igneous body now represented by the anorthosite cooled very slowly.

Very briefly stated, I consider the main steps in the development of the anorthosite to have been as follows: First, intrusion of a laccolithic body of gabbroid magma, only somewhat greater across than the exposed area of the anorthosite; second, relatively rapid cooling of the marginal portion to give rise to the chilled gabbroid border phase; and, third, settling of many of the slowly crystallizing femic minerals in the still molten interior portion of the laccolith, leaving a great body of magma to gradually crystallize into anorthosite. Thus, at the bottom, and probably nowhere visible in the field, lies a mass of pyroxenite or peridotite, next above it the thick body of Marcy anorthosite, and at the top and on the outer margins the chilled gabbroid border facies.

The chilled border phase merely represents the very outer and upper portion of the original gabbroid magma which solidified too rapidly to permit much settling of femic minerals from it. As Daly says: "The contact phase, a more or less continuous shell, thus represents the original magma." This marginal phase, of course, came into direct contact with the country rock (Grenville) and at first, when it was in its most highly fluid state, attacked the country rock with sufficient force to engulf portions of it, send some dikes into it, and even intimately penetrate it in

[48] R. A. Daly: Igneous rocks and their origin, 1914, pp. 229-243.
[49] F. W. Clarke: U. S. Geol. Sur. Bull. 491, 1911, p. 297.

some places, as in the Lake Placid quadrangle. For most part, however, the gabbroid magma was too stiff to cross-cut, penetrate, break up, and tilt masses of the Grenville strata in a manner at all comparable to the later syenite-granite magma.

Soon after the intrusion of the laccolith, femic minerals began to form toward its outer portion and to precipitate, thus permitting the accumulation of plagioclase in the upper levels of the magmatic chamber, but below and within the chilled border phase. Though this idea of the settling of femic minerals is much like that advocated by Bowen, my hypothesis differs in two important respects: First, the anorthosite did not form by settling of plagioclase crystals, and, second, there was no development of syenite-granite residual magma over the anorthosite. In my opinion, that portion of the magma from which the femic crystals settled was at first very largely, or wholly, molten, and then very slowly crystallized with continued precipitation of femic crystals until the magma became too viscous to permit settling of crystals. In other words, the anorthosite practically as such was actually to a very considerable degree molten, and it is not, as Bowen maintains, merely a mass of precipitated plagioclase crystals never, to at least a considerable degree, molten as such. It is not necessary to believe that there was any great amount of settling of femic constituents unless we assume a very femic original gabbroid magma, because fully 10 per cent of the femic minerals never precipitated at all, these being now present in the typical Marcy anorthosite.

According to my view, the femic constituents did not settle through anything like such a thick mass of magma as required by Bowen's hypothesis. Furthermore, only heavy femic minerals sank and not femic minerals followed by plagioclase in a magma which must have become increasingly viscous. These are, I believe, very important points. Regarding the settling of crystals in magmas in general, Iddings[50] says:

"The difference in density between the ferromagnesian minerals and the average magma is sufficient to cause them to fall through the action of gravity if the liquid were very fluid. But such magmas are more or less viscous near the point of saturation, the more siliceous ones exceedingly so. . . . The absence of evidence of any appreciable amount of settling of crystals in most solidified igneous magmas indicates that in these cases the viscosity of the liquid was such that no considerable precipitation could take place or that there were other hindrances."

It is evident, then, that the magma in the Adirondack region, out of which the femic constituents settled, must to the very last of the process

[50] J. P. Iddings: Igneous Rocks, vol. 1, 1907, pp. 270-271.

have contained at least a very considerable percentage of liquid of sufficient fluidity to allow the crystals to sink through, and this residual magma is represented by the present anorthosite, which was at least largely molten as such. Also it is clear that my hypothesis, which requires sinking of femic minerals only, in not very great quantities, through a moderate thickness of magma, is much more plausible than Bowen's, which requires sinking of femic crystals through a much greater thickness of magma, followed by a long process of wholesale settling of plagioclase crystals through a great thickness of the remaining magma. Could the magma have possessed sufficient fluidity long enough to have permitted this repeated process of crystal sinking, especially in view of the fact that no evidence points to more than a moderate degree of fluidity of the original gabbroid laccolithic magma?

Bowen strongly emphasizes two points: First, the failure to find anorthosite which consists of almost pure plagioclase in dike form, and, second, the failure to find an effusive equivalent of such anorthosite. The first statement needs some modification, as I have already shown, but I believe Bowen is correct in emphasizing these points. I do not, however, agree with Bowen when he maintains that these facts prove the anorthosite never to have been, to a considerable degree at least, molten as such. When we consider that the original gabbroid magma in the Adirondack region was probably not at a high enough temperature to be very free-flowing; that the marginal chilled border facies relatively soon developed to protect the still liquid interior portion, and that the anorthosite was not intruded as such, but was slowly formed by differentiation *in situ*—that is to say, by crystallization of the magma left after and during the precipitation of many of the femic minerals—it is easy to understand why the purer Marcy anorthosite has never been found in the form of dikes or small intrusive tongues.

But the fact should not be overlooked that some dikes of highly feldspathic border facies anorthosite (Whiteface type) do occur in the Adirondack region. In such cases, evidently, enough differentiation, probably by settling of femic minerals, must have taken place in the upper levels of the magmatic chamber to give rise to portions of magma possessing sufficient fluidity to be forced into the country rock in the form of dikes. There is, however, no reason to think that such dikes ever reached the surface of the earth, because the rather pure anorthosite magma thus formed did not, no doubt, possess sufficient fluidity long enough to penetrate very far into the thick country rock over the laccolithic magma. If anorthosites in general have originated by some such process as that here

outlined, and I believe they have, the failure to find the equivalent of the rather pure plagioclase anorthosite as effusive rocks is explained.

ORIGIN OF VARIATIONS IN THE ANORTHOSITE

The great body of Marcy anorthosite is by no means a homogeneous mass. There are many zones or belts and irregular-shaped portions, some distinctly more gabbroid and others distinctly more highly feldspathic than the typical Marcy anorthosite here and there throughout the mass. Many of these show relatively wide gradation zones into the typical rock, while others are more sharply separated. There are also many degrees of foliation and granulation and differences in coarseness of grain. These variations of the anorthosite and their significance have been somewhat fully discussed in a preceding chapter of this paper, the present purpose being to very briefly state two conceptions of their origin in the light of the hypothesis of the origin of the anorthosite presented in this chapter.

The view of the origin of such variations which best harmonizes with the field facts may be briefly stated as follows: During the crystallization of the anorthosite magma (formed by the process outlined above) there was local differentiation in the upper portion of the magma reservoir, whereby many portions relatively richer in femic constituents separated from the much larger portions relatively poor in femic constituents. The more femic portions, which contained more liquid, and hence were freer to flow, were in many cases more or less shifted by movements during a late stage of magma consolidation to form the crude bands or zones often well foliated and rather sharply separated from the purer anorthosite. Those belts or zones of more gabbroid anorthosite which gradually pass over into purer anorthosite probably represent differentiates essentially *in situ*. That there must have been notable movements during a late stage of solidification of the anorthosite magma is abundantly proved by the magmatic flow-structure foliation, more especially in the gabbroid zones, but not uncommonly in the typical Marcy anorthosite, and even in some portions of the nearly pure plagioclase anorthosite. In my opinion, these late stage magmatic movements caused much, or all, of the notable granulation of the anorthosite. But this granulation is by no means true only of the anorthosite. The syenite-granite series, and more especially the later gabbros, usually exhibit high degrees of granulation due to the same cause.

According to another view, we might imagine the more gabbroid zones to have resulted from upward shifting of small portions of more gabbroid magma from lower levels into the higher levels of purer plagioclase anorthosite. This implies upward shifting through at least thousands of feet

of congealing magma, which seems improbable under the conditions of the intrusion, differentiation, and consolidation of the magma. Also the very perfect gradations of many gabbroid zones into purer anorthosite are not so satisfactorily explained on this view.

Summary of Conclusions

1. The Adirondack anorthosite is a great laccolithic intrusive body, not very much greater in diameter than its present area of outcrop at the time of its intrusion.

2. The anorthosite is by no means a mass of practically pure plagioclase, the average rock (not including the marginal facies) containing fully 10 per cent femic minerals as well as smaller amounts of other significant constituents.

3. The anorthosite is distinctly separate from and older than the great syenite-granite series of the Adirondack region.

4. Many small dikes and small to large tongues of syenite and granite were forced into the anorthosite as offshoots from the distinctly later syenite-granite magma.

5. The anorthosite differentiated practically *in situ* from an intruded gabbroid magma.

6. A chilled gabbroid border facies developed both as an outer and an upper margin of the anorthosite.

7. The anorthosite crystallized from the upper or residual portion of the magma during and after the sinking of many of the femic constituents.

8. The anorthosite practically as such was, to a very considerable degree at least, actually molten.

9. There was little or no development of syenite or granite as direct differentiates of the anorthosite, particularly between the chilled border and the typical coarse grained anorthosite.

10. True transition rocks (Keene gneiss) between the anorthosite and the syenite-granite series were produced locally by magmatic assimilation of still hot, but not molten, anorthosite by the syenite or granite magma.

11. The border facies of the anorthosite not uncommonly sent dikes into, engulfed, or even locally injected portions of the country rocks (Grenville series), because this border facies represents that portion of the original gabbroid magma which came into contact with the country rock.

12. The rather common occurrence of inclusions of Grenville in the border facies and their practical absence from the typical coarse grained

anorthosite are also due to the fact that only the upper and outer portions of the laccolithic gabbroid magma effectively attacked the country rock.

13. The failure to find dikes of typical coarse grained anorthosite in the Grenville is because the rather thick border facies protected the Grenville against attacks by the coarse anorthosite, which, having developed from a residual magma, was either too viscous or too much crystallized to be sufficiently free-flowing.

14. Anorthosite, often highly feldspathic, is in places intimately involved with Grenville, giving rise to mixed gneisses quite comparable to the well known Grenville and syenite-granite mixed gneisses.

15. The variable gneissoid structure of the anorthosite was produced essentially as a magmatic flow-structure foliation.

16. The commonly occurring belts, zones, and very irregular masses of anorthosite-gabbro, and even gabbro, throughout the great body of the anorthosite probably represent local differentiates, some of which were more or less shifted by magmatic flowage and others not.

17. The more gabbroid portions of the anorthosite show more notable development of foliation because they longest retained very considerable percentages of liquid, but even the typical, coarse, nearly pure plagioclase anorthosite locally exhibits distinct foliation.

18. The notable granulation of the anorthosite was produced by movements in the magma during a late stage of its consolidation.

19. The relative absence of Grenville strata from the anorthosite area, particularly its southwestern half, as compared with its common occurrence throughout the syenite-granite areas, is explained, first, by the fact that the laccolithic anorthosite intrusion caused the Grenville to be mostly lifted or domed over its back rather than deeply penetrated, broken up, or engulfed as during the batholithic intrusion of the more highly fluid syenite-granite magma, and, second, probably because deeper erosion over the southwestern part of the anorthosite area caused complete, or almost complete, removal of the Grenville.

20. The general absence of the syenite-granite series from the anorthosite area, particularly its southwestern half, is best explained as due to great resistance of this the thickest portion of the relatively homogeneous anorthosite laccolithic body to the intrusion of the syenite-granite magma, as compared with the much slighter resistance offered by the surrounding Grenville strata. The notable absence of stocks of the later gabbro support this view.

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FIELD RELATIONS OF LITCHFIELDITE AND SODA-SYENITES OF LITCHFIELD, MAINE[1]

BY REGINALD A. DALY

(Presented before the Society December 29, 1917)

CONTENTS

INTRODUCTION

In 1892 Bayley gave a thorough petrographic description of the rare variety of nephelite syenite, litchfieldite, found in the town of Litchfield, Maine.[2] Since then this remarkable rock has been noted in the standard works on petrography. It was known only in the form of numerous boulders, which were moved from their parent ledges by Pleistocene ice. During the field seasons of 1916 and 1917 the writer visited the district with the aim of discovering, if possible, the bedrock source or sources of these erratics and therewith the structural relation of the igneous rock to the associated formations. The litchfieldite was found in place at two localities and other allied alkaline intrusives were discovered. The positions of most of the bodies are indicated by the accompanying sketch map (figure 1).

The area which was particularly studied is easily reached from the town of Gardiner by the electric car-line to Lewiston, shown in the middle

[1] Manuscript received by the Secretary of the Society December 12, 1917.

[2] W. S. Bayley: Bull. Geol. Soc. Am., vol. 3, 1892, p. 232.

of the map. Spears Corner is 6 miles (nearly 10 kilometers) from Gardiner.

Boulders of Litchfieldite

Little need be added to Bayley's account of the nephelite syenite composing the boulders. These may be readily recognized because of their

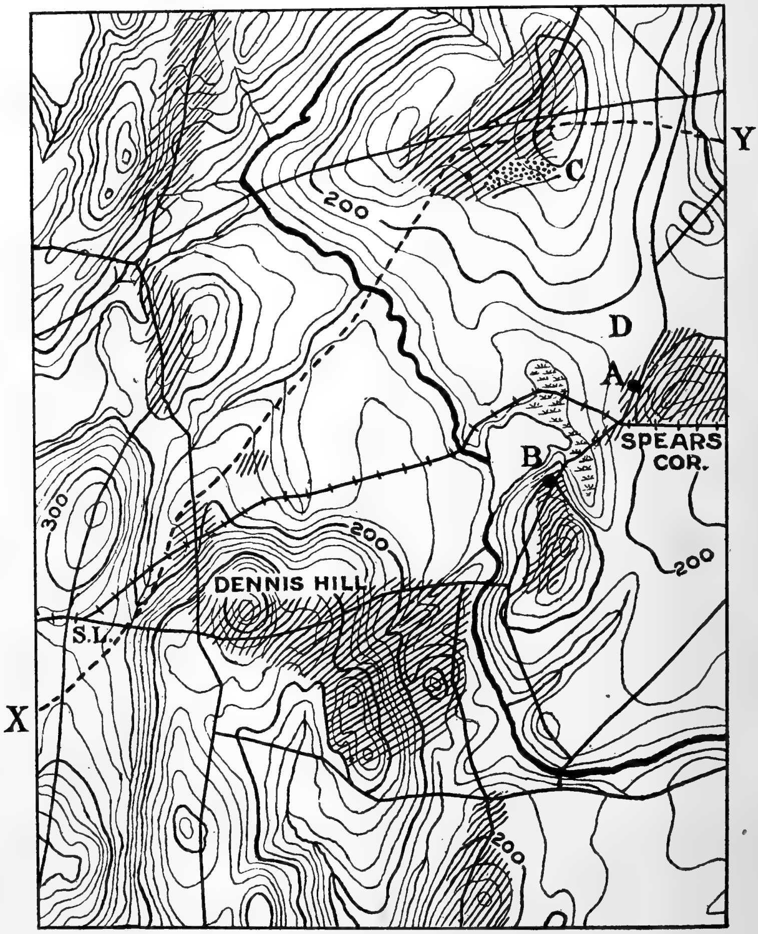

Figure 1.—*Location of Litchfieldite in Litchfield, Maine*

Exact position indicated by the dots marked *A* and *B*. Soda-syenites at *C* and *D* (fine dots). Areas showing outcrops indicated by shading, the lines drawn parallel to the strikes of the schists. S. L.—South Litchfield. Contour interval, 100 feet. Scale, 1 : —.

pitted surfaces, the pits being due to the specially rapid solution of the nephelite in rain-water. The rock is usually coarse and even pegmatitic,

so that the pits, like the associated feldspars, range from 1 centimeter to 8 centimeters in length. The content of nephelite is variable, from less than 1 per cent to more than 20 per cent of a boulder. Much less abundant are cancrinite and sodalite. The former seldom forms as much as 1 or 2 per cent of the rock and appears to fail entirely in most of the boulders when studied with the hand lens. The sodalite is still rarer, constituting isolated grains, narrow veinlets, and schliers. Most of the rock is composed of microcline, microperthite, microcline-microperthite, orthoclase, soda-orthoclase, and a lustrous lepidomelane with strong pleochroism in green tintes. Zircon and magnetite are rather rare accessories.

Bayley gives the following analysis of the boulder rock:

	Per cent
SiO_2	60.39
Al_2O_3	22.57
Fe_2O_3	.42
FeO	2.26
MnO	.08
MgO	.13
CaO	.32
Na_2O	8.44
K_2O	4.77
H_2O	.57
CO_2	tr.
	99.95

Calculated Composition (Bayley)

	Per cent
Albite molecule	46.92
Orthoclase molecule	27.01
Nephelite	17.04
Biotite	6.89
Cancrinite	1.99
	99.85

Details as to the chemical analyses and physical properties of the constituent minerals may be found in Bayley's paper.

Litchfieldite in Place

The glacial striæ of the region trend south 15° east to south 26° east, with an average trend of south 18° east. Neither in the many stone fences nor in undisturbed morainal deposits were boulders of nephelite syenite found to the northwestward of the broken line *X-Y* of figure 1. Search for parent ledges was therefore concentrated on the areas showing outcrops south of that line. Two separate bodies of the nephelite syenite *in situ* were discovered at the points marked with heavy dots, *A* and *B*. Since abundant boulders of the same material occur also to the northward and westward of *A* and *B*, it is certain that the litchfieldite is in place between the line joining those points and the line *X-Y;* but, as shown on the map, that part is quite lacking in outcrops.

Locality A is on the road, 310 meters north of Spears Corner. One considerable outcrop is in the middle of the road itself and another larger one is in a field a few meters to the west. Both are probably parts of one body, with total exposed length of 20 meters and exposed maximum width of about 10 meters. The litchfieldite is clearly intrusive into the adjacent schists, sending many tongues into them and inclosing shredded xenoliths (figure 2). On the north, east, and south outcrops are abundant enough to prove that the intrusive mass does not extend more than a few tens of meters in any of those directions. Its extension to the westward could

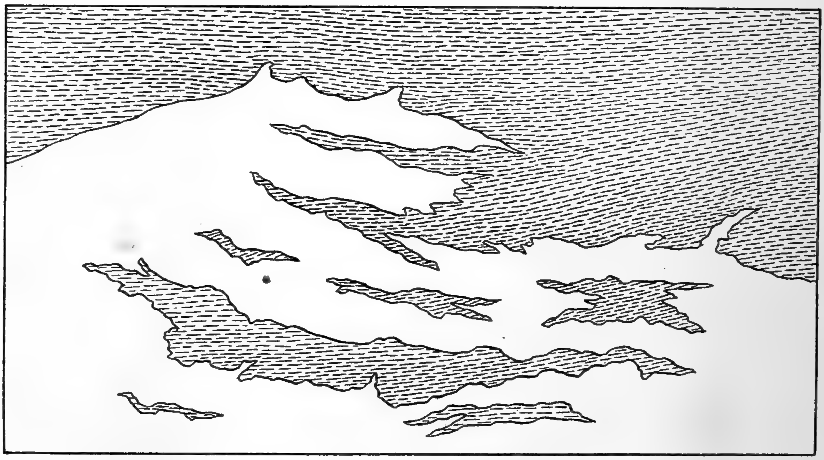

FIGURE 2.—*Schists (shaded area) cut by Litchfieldite (blank area) at Locality A, Figure 1*

Length of map represents 2 meters

not be determined. The maximum width of the body from north to south is less than 75 meters and is probably less than 25 meters.

The outcrop at locality B measures 30 meters from east to west and 18 meters from north to south. Here no actual contact with the invaded schists was seen, but mapping of the neighboring outcrops showed that this mass of litchfieldite is less than 50 meters wide and probably less than 125 meters long. The longer axis seems to be parallel to the bedding and schistosity of the inclosing formation, which strikes north 45° east, with steadily vertical dip.

Both bodies are probably short, thick pods, injected along the planes of the schists, though locally cross-cutting those planes. The concordance of the intrusives with the older structures seems to be like that manifested by the many quartz-pegmatite lenses of the region.

Petrographically, the litchfieldite of the two injections can not be distinguished from the normal rock of the boulders described by Bayley. In both cases cancrinite and sodalite are present as quite subordinate accessories. The museum specimens exceptionally charged with either of these minerals have been derived from local schliers in the boulder rock and do not represent typical litchfieldite. Apatite occurs in the ledge litchfieldite, though not reported by Bayley as in the boulders; on the other hand, zircon has not been identified in the ledge rock. Otherwise Bayley's description applies essentially also to the rock in place. The ledge rocks are strained and granulated to about the same degree as that illustrated in the boulders.

Soda-syenites

At locality *D* is a large exposure of a nephelite-free, alkaline syenite which is doubtless intrusive into the schists surrounding it. The outcrop measures 30 meters from east to west and approaches 10 meters in width. At locality *C* a much larger body of a closely similar syenite sends tongues into and incloses blocks of the schists. This intrusive body is at least 300 meters long and 75 meters wide. Its longer axis is parallel to the bedding of the sedimentary schists, here vertical and striking north 60° to 80° east. At one visible contact the eruptive is concordant with the schists, and there can be little doubt that it is a thick lens injected along the plane of schistosity. About 100 meters northwest of locality *B* is a third lens of the nephelite-free syenite, about 20 meters in maximum thickness. Judging from the distribution of glacial erratics composed of the soda-syenite, several other small intrusions not cropping out must be assumed in the area of figure 1.

These syenites are medium grained to coarse, often pegmatitic, and generally charged with large bent foils of biotite, identical in habit with the mica of litchfieldite. The feldspars are also the same, with a specially noteworthy development of untwinned, metamorphic albite in the crush-mosaics like those seen in the litchfieldite.

The large body at *C* is made up partly of this biotitic syenite, partly of an amphibole-bearing mica-free phase which appears to graduate into the former through mica syenite with accessory amphibole; the feldspars and subordinate accessories remain the same throughout. The amphibole, a new variety, is powerfully pleochroic, with tints of deep grayish blue and greenish yellow. The axial plane is perpendicular to the plane of symmetry. The extinction in the prismatic zone is everywhere sensibly zero. The amphibole obviously belongs to the alkaline series, and in its

properties approximates osannite. In one thin section are grains of a pleochroic, green pyroxene, probably ægirite. A little calcite appears to be primary.

Relation of Litchfieldite to the Nephelite-free Syenites and to Quartz Pegmatites

About 35 meters northeast of the litchfieldite outcrop at *B*, at the road, is an exposure of a coarse, pegmatitic syenite which is essentially the equivalent of the mica syenite except for the appearance of secondary muscovite due to crush metamorphism. Probably the two rocks form parts of a single intrusion. A close genetic connection between the two types is more evident in a large boulder occurring about 200 meters west of *A*. It is chiefly composed of coarse mica syenite bearing only a trace of nephelite, and in the hand specimen practically indistinguishable from the nephelite-free mica syenite in place at *C* and *D*. Within the dominant syenite of the boulder are narrow schliers of coarse, nephelite-rich litchfieldite. This combination suggests that the litchfieldite is, in part at least, a desilicated, pneumatolytic phase derived from a magma which normally crystallized as a feldspar rock free from nephelite.

Some of the nephelite-free syenite bears accessory quartz, and in one specimen quartz is pretty clearly of direct magmatic origin and must be rated as an essential constituent. Hence there is some ground for the hypothesis that all these syenites are, in origin, related to the much more abundant, common quartz-microcline pegmatites, which, as sills, lenses, and dikes, cut the crystalline schists of the district. The quartz-bearing pegmatites are strained or crushed about as conspicuously as the quartz-free injections.

Country Rocks

Throughout the area of figure 1 the intruded rocks form a comparatively uniform assemblage of rusty-weathering schists and micaceous quartzites, cut by numerous sills of orthogneiss. The schists are generally basic and rich in biotite. Abundant green hornblende, plagioclase, and orthoclase, as well as biotite, were found in one, apparently common, fine-grained phase of the crystalline complex. All transitions between biotite schist and typical quartzite seem to be represented, and one can hardly doubt the sedimentary origin of all these schists. No other sedimentary types were found in place, but several angular boulders, evidently not far from their parent ledges, were seen to contain thin beds of

limestone inclosed in the usual, well bedded mica schists. The orthogneiss seems to have been uniformly a common biotite granite.

Wherever observed, bedding and schistosity are parallel in the metamorphosed sediments. The dip is very seldom as low as 60° and is generally vertical. As indicated in figure 1, the strikes vary from north 30° east to north 80° east, with an average near north 45° east—the Appalachian trend. Because of the strong contrasts of the micaceous, quartzitic, and orthogneiss bands in their degrees of yielding to weathering agents, the usual outcrop of these steeply dipping beds is strikingly furrowed.

The age of the sediments is quite unknown, and no definite hint has yet been forthcoming as to the date or dates of the various intrusions. There is no reason for assigning any of the rocks to a date later than the Precambrian.

Summary of Field Relations

Outcrops in Litchfield are relatively rare. Hence thorough search by several observers has not yet afforded the data for a complete account of the litchfieldite. Judging from the visible masses and from the number and distribution of boulders, it is tolerably certain that there is no large mass of litchfieldite in the region. The celebrated boulders seem to have been derived from short, sill-like pods injected into the prevailing crystalline schists. The invisible lenses are probably little larger than the two so far discovered and have lengths measuring tens of meters or, at most, hundreds of meters, and maximum widths of a few meters or tens of meters.

The largest single injection observed, at *C* (figure 1), is a highly alkaline, but nephelite-free, syenite. This, like other syenite masses and like the much more abundant quartz pegmatites, seems to have been injected concordantly with the layering of the schists, though with local crosscutting. The igneous rocks may have been intruded before the upturning of the sediments. No information is yet at hand as to the precise conditions for the metamorphism of the various formations. Before the syenites and litchfieldite were injected the sediments seem to have been completely recrystallized, possibly through static metamorphism. The relative importance of dynamic metamorphism is most uncertain.

The coarse grain and general mineralogy of these igneous rocks strongly suggest that magmatic gases were largely concerned in their emplacement and in the concentration of the alkalies. Cancrinite in the litchfieldite and calcite, probably primary, in the soda-syenite tend to show that car-

bon dioxide was one of the gases involved. Chlorine participated in the formation of the sodalitic schliers; water in the formation of lepidomelane and other minerals. The influence of gases is further illustrated in the thorough impregnation of the schists by the litchfieldite magma for distances of 5 to 15 centimeters from the contact of schist and intrusive.

The origin of the magmas is a problem which can not be intelligently discussed without additional information concerning the petrography of the schist terrane and without a solution of the present mystery as to the nature of the terranes beneath the visible sediments. Further observations on the igneous history of the whole region are also necessary. Any future attack on the problem must include the consideration of three possibilities: (1) The magmas may be purely juvenile. (2) They may be purely resurgent, due to "selective solution" (Lane) among certain components of the visible schists or underlying formations. (3) The magmas may include both juvenile materials and resurgent materials—that is, country rock dissolved by juvenile magma. The cause of the local deficiency of silica, signalized by the crystallization of nephelite, cancrinite, and sodalite, is a related question. The small size of each of the undersaturated bodies is not a feature favorable to the prevailing dogma that nephelite syenite is a differentiate of a primitive magma specially rich in alkalies.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 29, PP. 471-488 SEPTEMBER 30, 1918

SEPARATION OF SALT FROM SALINE WATER AND MUD[1]

BY E. M. KINDLE

(Read before the Society December 28, 1917)

CONTENTS

Introduction

The following notes relate to laboratory observations by the writer on the behavior of salt in the evaporation of saline mixtures and to a discussion of their geological significance. The important bearing on geological theory of the phenomena resulting from the separation of salt from water and desiccated saline mud under experimental conditions is evident to the stratigrapher who has to interpret the meaning of salt crystal casts, mud-cracks, salt domes, and other features associated with the occurrence of salt in nature. The memoranda which follow relate to various experiments designed chiefly to permit observation of the features incident to the evaporation of salt water and to a discussion of geological phenomena on which they throw light.

Evaporation of saline Water

Saline water possesses the peculiar property of being able to circumvent the action of gravity and to ascend the vertical sides of any vessel in which it may be placed. This curious characteristic of salt water evidently represents a phase of the phenomena of capillarity. It is not immediately active or apparent on filling a vessel with salt water. If, however, an ordinary drinking glass is filled three-quarters full of brine, it will be

[1] Manuscript received by the Secretary of the Society January 23, 1918.
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noted in a few days that a thin film of salt has formed a narrow linear band around the inside of the glass and extended above the original surface of the water. This film widens through evaporation of the water around the sides of the glass, depositing a layer of salt on the glass just above the upper margin of this film. The film of salt continues to advance slowly upward by capillary attraction and subsequent evaporation of saline water until the top of the glass is reached. It then in the same manner grows downward and eventually covers entirely the outside of the vessel. If the supply of saline water is renewed from time to time, the

FIGURE 1.—*Salt Efflorescence*

The efflorescence has completely covered five vessels through the creep of the salt water over the sides of the innermost vessel

water will be found to flow out of the glass quite rapidly after the salt incrustation is well developed and down over the outside in a continuous trickling sheet. The glass if set inside a series of larger vessels will in this way cascade its saline contents into each one in turn through the medium of the salt film. Constant thickening of the salt layer on each of the vessels is a concomitant feature of this barrier-climbing process. The salt incrustations on the five vessels shown in figure 1 were produced by placing salt water only in the inner vessel, from which it slowly cascaded into the others.

Another illustration of the ability of salt in solution to escape from any open containing vessel in which it may be placed is furnished by a second experiment which was designed originally to elucidate another subject. A tube was used in which clay and sandy materials were deposited from a saline solution. A bit of pine stick was left standing in the top of the tube until the water had completely evaporated. It was then observed that the salt had also entirely left the tube, so far as the eye could detect, and formed an incrustation about the upper part of the stick. Although the surface of the salt water containing suspended clay was never higher than one inch below the top of the tube, the salt as the water evaporated formed an incrustation which extended nearly an inch above the original surface of the water. In another experiment an open fruit jar was partly filled with saline water which was allowed to evaporate slowly. The supply was renewed from time to time till the upward creeping salt had entirely closed the mouth of the jar and formed a considerable mass above it, as seen in figure 2. The dome which completely closed the top of this jar was found to have a maximum thickness of about $1\frac{1}{2}$ inches, but showed no crystals. The bottom of the jar was covered to a depth of about one-half inch with salt crystals from one-sixteenth to one-eighth inch thick.

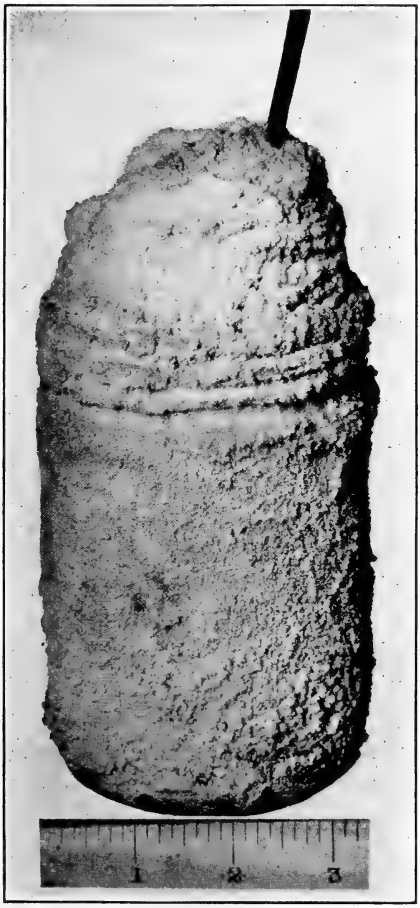

FIGURE 2.—*Salt Efflorescence*

The glass jar was kept partially filled with a saline solution until the ascending salt had completely closed the mouth and coated the outside. $\times \frac{1}{2}$

These examples illustrate a process which must be continually in progress on the seacoast, particularly in dry climates, through which on rocky shores large quantities of salt are separated from the sea-water and become subject to the action of the wind. Such incrustations would be

easily removed by wind-driven sands and carried inland to indefinite distances.

In recent years the view that many salt lakes have derived most of their salt from the sea through the agency of the wind has gained ground over the older opinion that the salt of such lakes had been gathered from their drainage basins as a result of land-locked drainage. The trend of the former view is illustrated in Ackrad's[2] conclusion that the salt of the Dead Sea has been carried by the wind from the Mediterranean Sea.

R. Angus Smith has shown that the amount of salt in rain-water varies with the distance from the sea.[3] In the salt desert region of India even the dew which collects on the Faras trees is said to be distinctly saline.[4]

Prof. J. B. Woodworth has called my attention to a map of the State of Massachusetts[5] which shows by "isochlorine lines" the normal chlorine of ground waters from the seaboard inland, varying from 2.16 in 100,000 parts on Nantucket to .07 at the New York line.

The photographs here shown (figures 1 and 2) support the newer views regarding the origin of salt lakes to the extent of showing the marvelous facility with which salt separates itself from saline solutions and forms deposits which are most accessible to wind action.

It may be pointed out here that the activity of the migratory tendency which characterizes the behavior of salt in aqueous solutions is not confined to subaerial conditions. The peculiar features in the behavior of saline water which have been described are worthy of careful consideration by the geologist, for because of them the opening of a fault-line or joints to a bed of salt at any depth would afford a means of its escape or migration upward. The same tendency which enables all of the salt in a glass tube to remove itself from that tube by ascending the sides of a pine stick, as already described, or to form a cap at the top of a glass jar would cause it to migrate laterally or vertically through the rocks which possess the proper porosity to admit of the movement of water which would aid in such a transfer. We should therefore expect salt deposits to remain in the beds where originally laid down only when these beds are sealed by impervious clays or other beds, as in the Salina formation. It is quite possible for the migratory propensity of salt in many instances to cause its transposition to a part of the geological section remote from the horizon of its original deposition. The great salt domes of the Louisiana

[2] Chemical News, January 8, 1904, p. 13.

[3] Air and rain, p. 263.

[4] T. H. Holland and W. A. K. Christie: The origin of the salt deposits of Rajputana. Rec. Geol. Surv. of India, vol. 38, 1909, p. 166.

[5] Twenty-second Ann. Rept. of the State Board of Health of Massachusetts. Public Document No. 34, Boston, 1891.

salt district appear to afford examples of such migration of salt upward in great quantities. Isolated domelike masses of salt more than 2,000 feet thick occur there in beds of Quaternary age[6] which have evidently been derived from older beds through the agency of salt-bearing waters rising along fault-planes and depositing their salt at the intersection of the faults.[7] The salt hill south of Algiers, in Africa, which has been described by Ville,[8] appears to be another example of a great secondary salt deposit.

The shallow salt lakes of northern Patagonia, with floors of salt 2 or 3 feet in thickness, described by Charles Darwin,[9] illustrate the conditions under which some of the continental deposits of salt are now accumulating.

Salt Separation by Freezing

It is a familiar fact that the freezing of saline water is accompanied by a partial mechanical separation of the salt. In the case of sea-water, Mawson,[10] in recording his observations in the Antarctic on this subject, states that "the sea-salt mechanically separates from the ice as the latter forms and is partially forced out into the sea-water below and partly included in white, vertical tracts between the ice prisms. . . . During the formation of surface ice some of the sea-salts are squeezed upward through capillary cracks to the surface and then, in the form of concentrated brine, eventually freeze as cryo-hydrates and form nuclei from additions from atmospheric water vapor." These are the ice-flowers of Captain Scott.[11] Regarding the salt lakes of the Antarctic, Mawson reports that "as refrigeration goes on in the lakes, the saline contents are gradually concentrated in the residual liquid and a continuously increasing cold is required to freeze each succeeding separation. Ultimately a meshwork of ice and cryo-hydrate crystals are formed at the bottom of the lakes. As some of the lakes are very saline, this cryo-hydrate often bulks large. Some of it freezes at as low as a temperature of 50 degrees Fahrenheit below freezing point."

A salt deposit in the Salt River valley of the Northwest Territory, Canada, which was recently examined by the writer, shows that small deposits of salt may, chiefly through the freezing of salt spring water,

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[6] G. D. Harris: Bull. Geol. Surv. of Louisiana, No. 7, 1908, pp. 15, 24.
[7] Ibid., pp. 79-81.
[8] Ann. des Mines, 5th ser., vol. 15, 1859, p. 365.
[9] Jour. Researches during the voyage of the *Beagle,* 1860, p. 75.
[10] Douglas Mawson: Notes on physics, chemistry, and mineralogy. The heart of the Antarctic, by E. H. Shackleton, vol. iii, 1909, pp. 354-359.
[11] Capt. R. F. Scott: The voyage of the *Discovery,* vol. i, pl. opp. p. 268.

accumulate under subaerial conditions more rapidly than it can be removed by denudation in a climate which is far from arid. The Salt River is a small tributary of Slave River, which it joins from the west about 170 miles south of Great Slave Lake. A flat plain 4 or 5 miles wide, through which Salt River flows, is characterized by highly saline springs which flow from limestones of Devonian or Silurian age. The region is characterized by a heavy snowfall and a rather large summer rainfall, but the precipitation fails to prevent the accumulation of considerable masses of salt near some of these springs. In front of one spring visited by the writer there was a mass of salt about 40 feet by 15 feet, with an average thickness of about 10 inches. More than 100 sacks of salt are annually taken from this deposit by the people of the district. But the supply is promptly renewed. A considerable portion of this salt bed rises a few inches above the flat sun-cracked saline mud which immediately surrounds it. Most of this salt doubtless accumulates through its mechanical separation by freezing of the saline spring waters during the winter, when temperatures often as low as 60 degrees Fahrenheit prevail. It is doubtless also receiving continuous accretions from the saline mud under the deposit in summer; from the spring water flowing under it and from the damp salty mud near by it probably adds constantly to its volume in the same way that the mass of salt which seals the fruit jar in figure 2 was accumulated.

At La Saline, on the Athabasca River, McConnell[12] has reported a small deposit of salt formed by a saline spring, which also deposits gypsum and native sulphur.

The occurrence of subaerial deposits of salt like the Salt River deposits in the Northwest Territory and the separation of salt from salt lakes at winter temperatures in high latitudes place in the category of conditions favoring the natural formation of salt deposits, alongside of high temperature and aridity, very low temperatures acting under average conditions of precipitation.

Formation of Salt Crystals

At temperatures of about 85 to 110 degrees Fahrenheit, evaporation of a saturated solution of salt results in the formation on the surface of the brine of cubical or prismatic forms in which the upper surface is depressed into an inverted pyramid. This hopper-shaped depression always develops on the uppermost side of the figure and causes it to float during the early stages of crystal growth or until it is overturned, when it imme-

[12] Canada Geol. Surv., vol. v, pt. i, 1893, p. 35D.

diately sinks. A slight jarring of the water when these crystals are forming results in many of the smaller ones showering to the bottom. Crystals of this type after sinking to the bottom perfect the cubical shape by growing a thin layer of salt over the base of the inverted pyramid, thus leaving a hollow pyramid inside the cube of salt in which water is often inclosed. Salt crystals formed at temperatures about 110 degrees are apt to be larger than those formed at lower temperatures. They usually develop at the surface of the brine from a very small initial cube of salt, which is partially submerged by the growth from its four upper angles of four other small cubes, to each of which still others are added. A thin

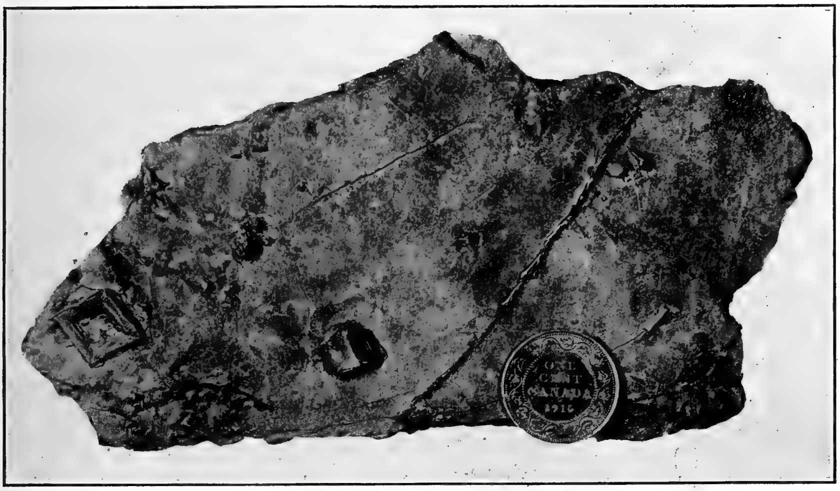


FIGURE 3.—*Pseudomorphs of Salt Crystals*

The crystals occur with hopper-shaped faces on buff-colored Cambrian dolomite from Roche Miette, Jasper Park, British Columbia. × ¾

walled, transversely striated, inverted pyramid results, whose angles are formed of miniature superposed cubes.

An interesting feature of salt crystallization is the control exercised over the crystal form by the temperature at which evaporation and crystal growth occurs. Salt crystals formed under a temperature of 70 degrees Fahrenheit or lower were all of cubical, tabular, or prismatic form in my experiments. When the crystals are formed by evaporation at higher temperatures instead of the cubical and prismatic forms, hopper-shaped crystals are produced. Most of the salt crystal pseudomorphs in sedimentary rocks which have come under my notice are of the pyramidal or hopper-faced cube type, like those shown in figure 3, and hence appear to furnish evidence of their formation under the influence of warm climatic

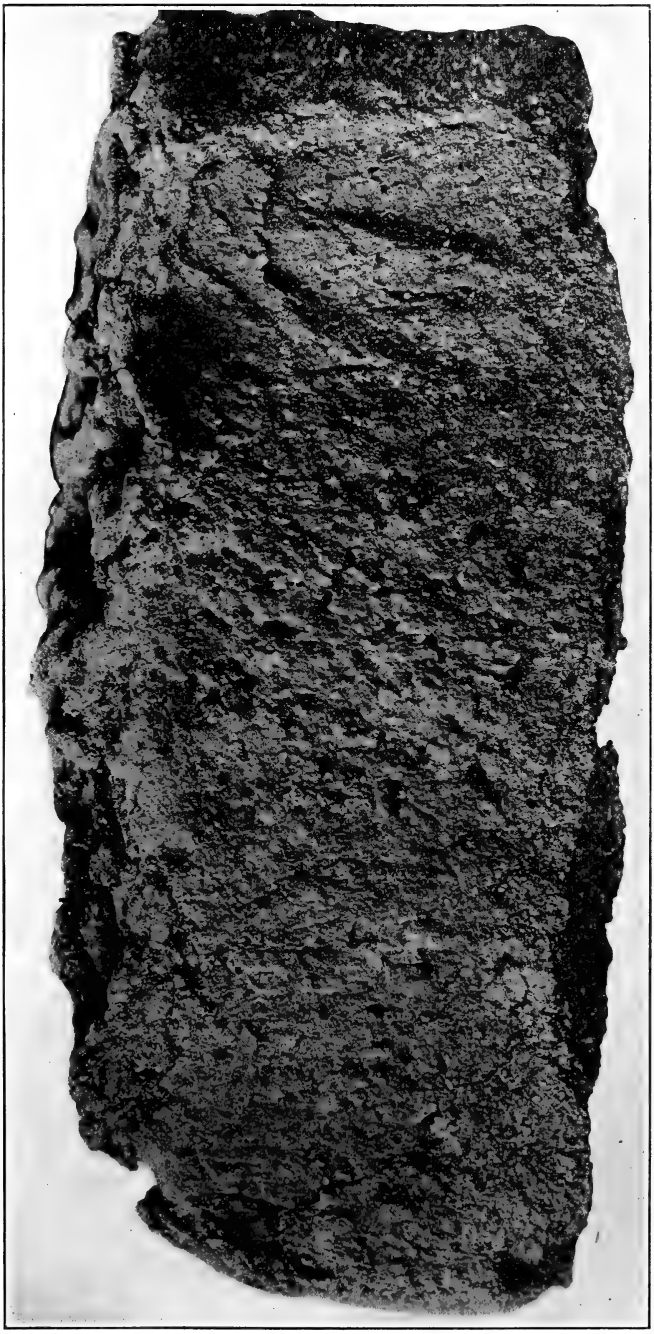


FIGURE 4.—*Desiccated saline Clay from Salt River, Northwest Territory*

Showing vesicular texture. × 2

conditions. The subject of the control of crystal form and size by temperature is, however, one which demands a more exhaustive and detailed series of experiments than those here discussed before any positive geological deductions are warranted. It is a subject which invites further investigation.

Desiccation of saline Muds

In an experiment undertaken for the purpose of observing the separation of salt from mud during slow desiccation the fine textured blue Pleistocene clay of the Ottawa Valley was used. A quantity of finely divided clay was added to a saturated solution of salt which was placed in a small aquarium bowl. The bowl was used rather than a shallow pan in order to give a much longer time for evaporation and separation of the salt. A temperature between 85 and 100 degrees was maintained until the water had evaporated down to the surface of the semi-fluid mud. The desiccation of this material yielded a layer of dry mud three-fourths of an inch thick, covered by about one-half an inch of salt. The complete drying of the mud, even with the aid of the electric fan for a portion of the time, required more than two months—a period more than three times as long as a fresh-water mixture would have required. The separation of salt from mud during its desiccation resulted in three somewhat different varieties of salt. The topmost layer was a pure white incrustation of salt which first covered the surface of the mud. This consisted of minute crystals covering the surface with an irregular frostlike effect. Immediately below this another salt layer formed, which consisted of slender acicular vertical crystals holding a small amount of argillaceous matter in the lower part, which gave them a dull gray color near the mud. These acicular salt crystals also filled some of the first mud-cracks which formed. These mud-cracks which were lined with the thin salt plates and needles would if filled with fine sand or mud have duplicated in appearance the unusual looking mud-cracks which were called *Dictuolites beckii* by Conrad and Hall.[13] There can be little doubt that these peculiar looking structures which were supposed to be of organic origin represent mud-cracks which were formed in saline muds. The third form in which the salt separated from this mixture gave rise to cubical crystals with hopper-shaped faces, similar to those of the pseudomorphs shown in figure 3. These were scattered sparingly through the dry mud and occurred in the smaller mud-cracks. These crystals in the desiccated mud had a diameter usually between 2 and 4 millimeters and frequently produced cracks in the mud radiating from the angles of the cube.

[13] Paleontology of New York, vol. ii, 1852, pl. 3, fig. 1.

In saline mud which holds a very small percentage of salt, desiccation produces only a thin film of saline matter on the surface similar in color to the mud and neither cubic nor acicular salt crystals are formed.

An interesting feature of the desiccated saline mud is the presence throughout the material of numerous minute cavities. These cavities were first noted in experimenting with the Pleistocene blue clay, where

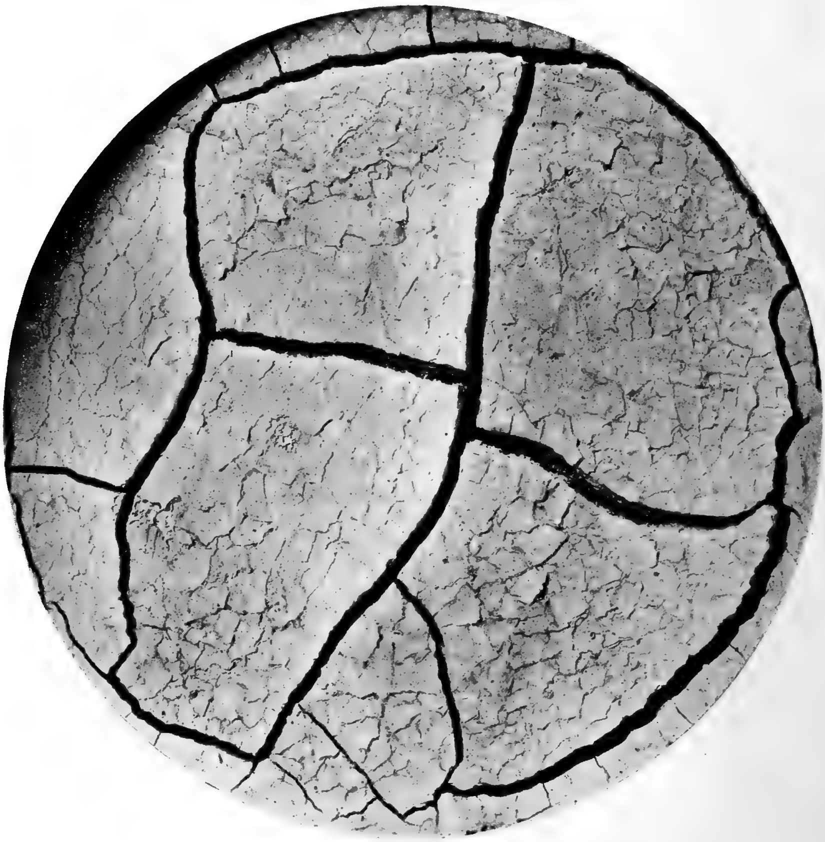


FIGURE 5.—*Mud-crack in a fresh-water Mixture of slaked Lime*

they had usually a diameter of from one-third to one-half a millimeter. Desiccated mud made with fresh water from the same clay showed no trace of the cavities, thus indicating that this feature was due to the presence of the salt. This remarkable contrast between the texture of desiccated mud containing salt and the texture of dried mud free from salt was verified by a number of tests in which clay from the bottom of Lake Ontario was used. In these tests duplicate lots of mud were desiccated in

vessels of the same size, the same quantity from the same mixture being used in the parallel tests. The salt which was added to one sample in each case was the only factor which was allowed to differ in the two lots. In each case the dry saline mud showed numerous small cavities which were absent in the corresponding sample of fresh-water mud.

The mud-cracked clay of the salt playas of the Salt River valley shows very clearly the same peculiarity, the sun-baked saline mud being closely pitted with numerous very minute cavities and irregular pipelike passages (figure 4).

Considerable geologic importance attaches to this feature because it is one which would in many cases almost certainly be preserved permanently in the rocks. It should therefore furnish in the case of fine-textured clastics deposited under subaerial conditions decisive evidence as to whether they originated in saline or fresh waters.

In another experiment, instead of mud a mixture of air-slaked lime and water was used. One quart of powdered air-slaked lime was placed in each of two pans and mixed with about 2 quarts of water and left to desiccate in a temperature ranging from 75 to 90 degrees. A small quantity of salt was mixed with the contents of one pan; in other respects the two mixtures were identical in kind and amounts of constituents. The first mud-crack appeared in the fresh-water pan four days after preparing the mixture. This pan was completely mud-cracked four hours after the first crack appeared (see figure 5).

The salt mixture, though apparently dry on top, showed no trace of mud-crack for nearly two days after the development of mud-crack in the fresh-water pan. On the sixth day, however, the surface of the saline mixture showed weak lines slightly depressed, but not actually cutting the surface, which marked it into numerous small polygons. One week after starting the desiccation these lines had become more sharply defined, but were otherwise changed but slightly. In this more completed definition they formed very shallow V-shaped valley-like lines of depression, which marked the surface, and the surface only, into polygons (see figure 6)—that is, they had no appreciable downward extension like ordinary mud-cracks and the polygons were flat, except for the slight down-beveling of the edges adjacent to the lines separating them. The fresh-water mud-crack did not change after the day it appeared, except that the intervals between the polygons widened slightly. They showed a width of from one-eighth to three-eighths of an inch. The larger polygons developed around the margin an upwarp of about one-fifth of an inch.

It is apparent from these experiments that the development of mud-cracks in calcareous mixtures proceeds as in ordinary mud, and that lime

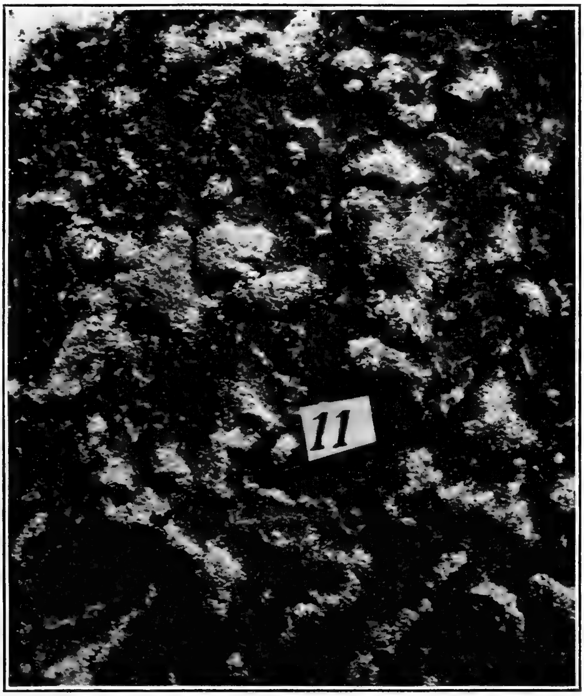
muds show the same contrasts in saline and fresh water as non-calcareous mud. The flat polygons and linear character of the mud-cracks in the saline mixture are in sharp contrast with the upwarped fresh-water polygons separated by broad spaces. This difference between fresh and saline mud-cracks has been discussed elsewhere.[14]

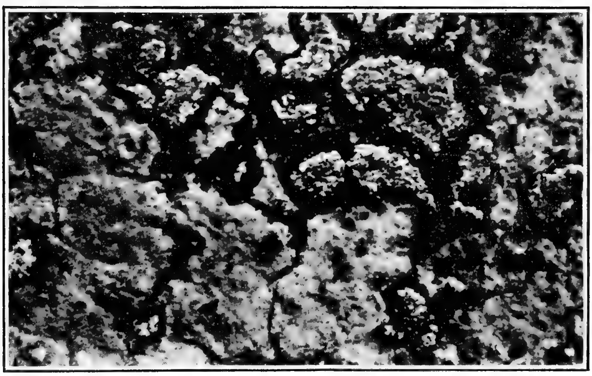
FIGURE 6.—*Mud-crack in a salt-water Mixture of slaked Lime*

In their lack of depth and in their surficial character the mud-cracks in the saline lime mud strongly remind one of the mud-crack, which is a common feature of the Pemalia limestone at Kingston, Ontario. A very characteristic feature of the Pamelia limestone near Kingston is the presence in the lower half of the formation of beds with very perfectly preserved sun-cracks (figure 12). They occur in limestones of very fine,

[14] E. M. Kindle: Some of the factors governing the formation of mud-crack. Journ. of Geol., vol. 25, 1917, pp. 135-144, figs. 1-6.

even texture. Although sharply outlined on the surface of some of the beds, they do not penetrate any perceptible distance into the limestone.





FIGURES 7, 8.—*Desert Salt Crusts*

From the edge of the desert near Trigo, California. Photograph by Dr. M. I. Goldman.

Sun-cracks occur in quarries on the north side of Kingston at various horizons in the Pamelia. Associated with the sun-cracks in some of the

quarries numerous elevations occur rising from 1 to 3 inches above the adjacent flat sun-cracked surface. These curious depressed little hummocks vary from a few inches to a couple of feet in diameter and have a highly irregular outline in most cases. They are cut like the adjacent surface by sun-cracks.

These miniature hummocks on the mud-cracked beds of the Pamelia limestone are probably related in origin to and are somewhat comparable in appearance with the curious elevations found on the surface of the mud in certain localities, known as "self-rising ground," on the playa clays of the Southwestern States, which have been photographed by Dr. M. I. Goldman. Concerning these photographs (figures 7, 8), which I

FIGURE 9.—*Mounds of Clay on Salt Plain west of Fort Smith, Alberta*

am able to reproduce through the courtesy of Doctor Goldman, he writes as follows: "I find in my notebook the following concerning the photograph numbered 11: 'Bulged salt crusts at edge of desert at Trego, hummocks white, intervening flat portions blue gray clay.' Evidently, therefore, the white portions on the picture are essentially salt, though they would doubtless contain some clay impurity."

Some features observed during a recent visit to the salt plains of Salt River, Northwest Territory, appear to fall in the same general category with the Pamelia limestone hummocks and the "self-rising ground" of the southwestern playas. Several hundred acres of the flat plain in the vicinity of the salt springs of Salt River are entirely destitute of vegetation and afford exceptional opportunities in midsummer for observing

phenomena connected with the desiccation of saline mud. These areas are more or less completely covered with waters from the saline springs in the spring and early summer. The wide expanse of mud-cracked surface which late in the summer develops with the disappearance of the water from the salt plains shows in certain areas peculiar little mounds of saline clay (figure 9). These vary in height from a few inches to a foot or more and over limited areas are spaced at intervals of 1 to 4 feet. They differ from Goldman's "salt crusts" in being essentially clay with only a trace of salt. Several of these mounds were cut into, all of which showed at the base a core of dark vegetable matter which appeared to represent a variety of bunch grass. Evidently the development of these

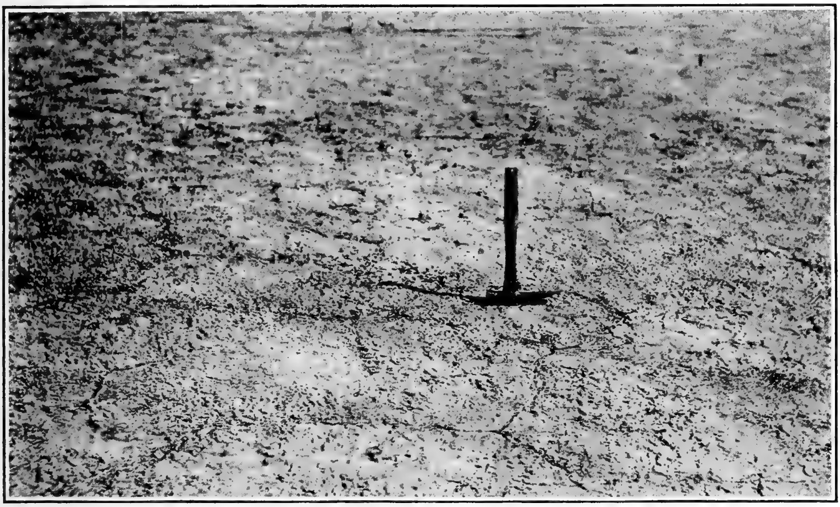


FIGURE 10.—*Mud-crack with corrugated Surface, Salt River, Northwest Territory*

Salt River miniature clay mounds has started through the agency of small detached patches of grass or other vegetation which, gaining a temporary foothold on the saline clay, were later overwhelmed with saline efflorescence and incrustations and turned gradually into mounds of clay or mud through the periodic leaching out of the salt, leaving behind the argillaceous matter which accumulated with it. The capacity of saline water for surrounding and incrusting any upright object with which it comes in contact has been illustrated in the first part of this paper. Grass, algæ, or other vegetable materials would serve as nuclei for large saline incrustations quite as well as the materials used in the experiments. It has also been experimentally shown that the basal layers of salt efflorescing on mud draw up with them some of the mud.

Another variety of surface configuration which is occasionally seen on the Salt River salt plains is an irregular flat-topped elevation usually 6 or 8 inches in diameter, which rises only an inch or two above the surface of the mud-crack polygons on which it occurs. These closely resemble in their irregular outline, slight elevation and association with mud-crack, the Pamelia limestone mud-crack hummocks described above. Some species of algæ probably acts as a nucleus for the development of these biscuit-shaped masses.

Large areas of the mud-crack polygons of the Salt River salt plains have a deeply corrugated surface (figure 10). This peculiar surface is

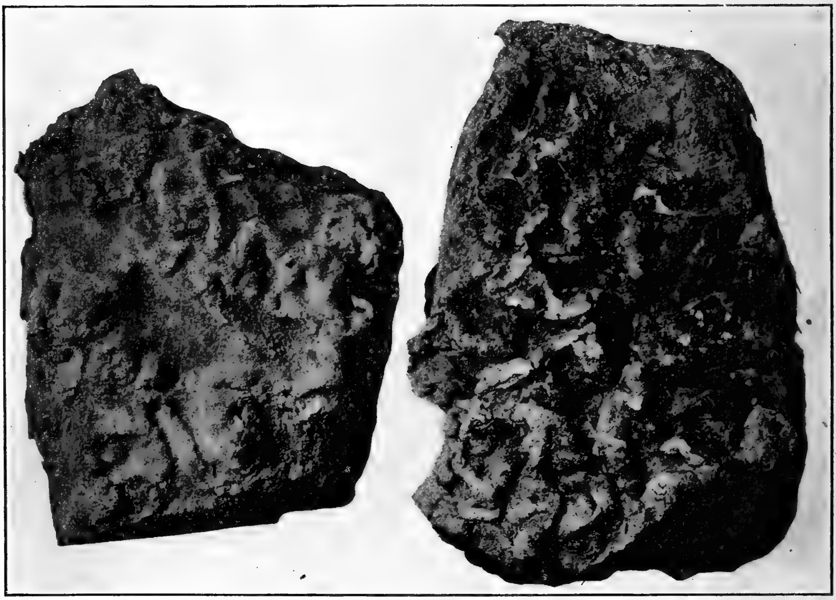


FIGURE 11.—*Desiccated saline Clay with dried Algæ, Salt River, Northwest Territory*
Half natural size

due to a species of algæ which evidently grows over large areas of the plain when it is covered by water. After the drying up of the playa the shrinkage of the algæ, combined with the irregular efflorescence of the subsurface salt and saline mud which it develops, results in the innumerable closely spaced zigzag ridges one-fourth to one-half an inch in height (figure 11).

In the Salt River playas two types of mud-crack are common. In one the polygons are marked by lines which are distinct and sharply defined, but which, as in the Kingston mud-crack, scarcely cut below the surface.

In the other type the mud-cracks are much wider and extend downward one or more inches. The latter are found over the larger part of the area and characterize the clay with a comparatively moderate amount of salinity. The former are found near the salt-water brooks which cross the playa where the clay is highly saline.

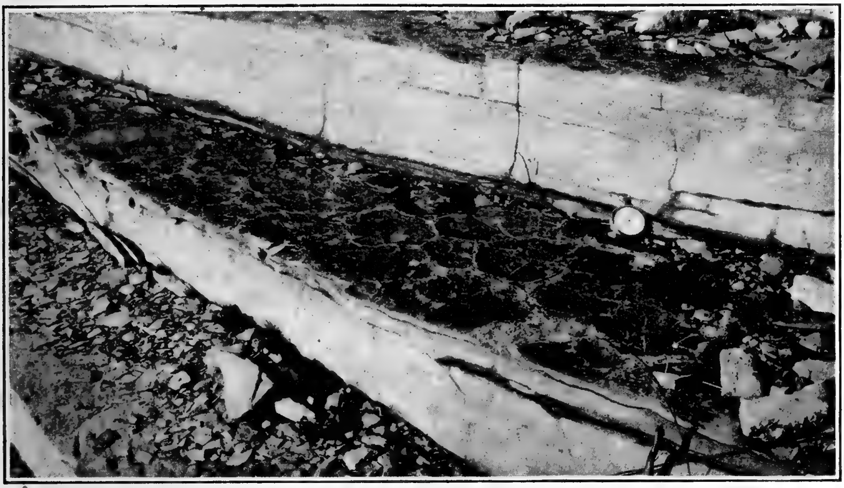


FIGURE 12.—*Mud-crack in Pamelia Limestone, Kingston, Ontario*

Photograph by Dr. Kirtley F. Mather

It would appear from these observations that the Pamelia limestone mud-crack, with its slightly incised lines, represents highly saline muds, while the type illustrated by the Mount Wissick[15] limestone mud-cracks extending several inches into the rocks were formed in calcareous mud of slight or moderate salinity.

[15] E. M. Kindle: Canada Geol. Surv., Mus. Bull. No. 14, 1914, pp. 35-39, pls. ii-iii.

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SUBSIDENCE OF REEF-ENCIRCLED ISLANDS[1]

BY W. M. DAVIS

(Presented before the Society December 27, 1917)

CONTENTS.

[1] Manuscript received by the Secretary of the Society February 4, 1918.

Darwin's Verifications of the Theory of Subsidence

UNEXPLAINED CONFUSION REPLACED BY REASONABLE ORDER

It has sometimes been objected to Darwin's theory of upgrowing coral reefs on intermittently subsiding foundations, that he gave no independent proof of the subsidence which he postulated; but as a matter of fact he brought forward three kinds of confirmatory evidence for it. He showed, first, that the sequence of forms which includes fringing reefs, barrier

reefs, and atolls finds a simple and rational explanation in the processes that the theory of subsidence involves, and thus gave to the theory the recommendation of bringing reasonable order out of unexplained confusion. This evidence is of the same kind that he employed some 20 years later when he wrote in the "Origin of Species": "I believe in the doctrine of descent with modification, notwithstanding that this or that particular change of structure can not be accounted for, because this doctrine groups together and explains . . . many general phenomena of nature."

ACCORDANT DISTRIBUTION OF DIFFERENT KINDS OF REEFS

Darwin showed further that coral reefs, as known in 1840, were distributed in such a way as to associate barrier reefs and atolls in certain large regions, and fringing reefs in certain other large regions; and as on the one hand the reefs of barriers and atolls were taken to indicate subsidence, and on the other hand fringing reefs were, as a rule, taken to indicate upheaval, the occurrence of the two groups of reefs in separate large regions was regarded as accordant with the manner in which subsidence and upheaval were supposed to operate in deforming the ocean floor. "We may, therefore, conclude," Darwin wrote, "that the proximity in the same areas of the two classes of reefs [barriers and atolls], which owe their origin to the subsidence of the earth's crust, and their separation from those [fringes] formed during its stationary or uprising condition, holds good to the full extent which might have been anticipated by our theory" (1842, 125).

The distribution of reefs, as known today, does not bear out this conclusion, for reefs of different kinds are found to be intermingled in a much more intimate manner than Darwin believed; and many fringing reefs occur in areas of strong and recent subsidence, where they appear to have been formed in a manner which Darwin clearly recognized, although he thought it exceptional, as will be shown below. But it may be added at once that, as far as detailed studies such as those of Foye in Fiji (1917) have been made in recent years, they show that, even in regions of complicated movement, reef formation has been associated with subsidence; thus confirmation has been found recently for Darwin's theory precisely in those regions which have been thought to contradict it.

DEEP LAGOONS INCLOSED BY BARRIER REEFS

Darwin also pointed out that the occurrence of barrier reefs, "in some cases steep on both sides like a wall, at a distance of two, three or more miles from the shore, leaving a channel [lagoon] often between 200 and 300 feet deep," is inconsistent with their formation on stationary foun-

dations; and to this he added, rightly disregarding solution as a process for the production of lagoons: "The existence, also, of the deep channel utterly precludes the idea of the reef having grown outwards on a foundation slowly formed on its outside by the accumulation of sediment and coral detritus" (49). He noted, furthermore, that "a considerable degree of relation subsists between the inclination of that part of the land which is beneath water and that above it," and therefore constructed profiles in which the visible slopes of high islands were prolonged beneath sealevel as a means of determining the depth of barrier-reef foundations, and concluded that "the vertical thickness of these barrier coral reefs is very great" (47). But as this line of evidence was not closely discussed, it is here further considered on a later page.

ABANDONMENT OF THE THEORY OF SUBSIDENCE

It is true, however, that the theory of upgrowing reefs on intermittently subsiding foundations did not gain a satisfying amount of independent verification at Darwin's hands. The acceptance of the theory through the middle of the nineteenth century as presenting the only possible origin of coral reefs was based chiefly on the insufficient ground that it explained the facts which it was invented to explain. Hence, when apparently competent alternative theories were brought forward about 1880, many former believers in Darwin's theory lost confidence in it; but, illogically enough, they thereupon adopted one or another of the newer theories, although these were as little supported by independent verification as Darwin's was. It was as if they said: "The peculiar features of coral reefs, which we have hitherto thought could be explained only by Darwin's theory of upgrowth on subsiding foundations, are now shown to be explicable by outgrowth from non-subsiding foundations. Subsidence is therefore no longer a necessary condition of reef formation; hence subsidence did not occur. We therefore abandon Darwin's theory and adopt the newer theory." It would have been more reasonable to say: "Now that two or more possible origins for coral reefs have been suggested, let us seek means of critically determining which suggestion best represents their actual origin."

This course was seldom adopted. Thus Sir A. Geikie declared: "No satisfactory proofs of a general subsidence have been obtained from the region of coral reefs. . . . In face of the evidence which has now been accumulated, I can no longer regard the accepted theory [Darwin's] as generally applicable" (1883, 27). Hahn stated: "So reiht sich Tatsache an Tatsache um uns zu überzeugen, dass Darwin's Korallentheorie, an der noch vor wenigen Jahren kaum jemand zu rütteln wagte, jetzt aufge-

geben werden muss" (1883, 190). De Lapparent announced: "Il ne semble pas que le phénomène corallien réclame, comme condition essentielle, une mobilité générale du lit de l'océan," and he therefore gave up Darwin's theory (1885, 560). Perrier wrote that the reef around Tahiti "s'explique facilement sans qu'il soit nécessaire de faire intervenir aucun affaissement. . . . On ne croit donc plus à un lent affaissement de tout le fond du Grand Océan" (1887, 24?). Murray concludes: "It seems impossible with our present knowledge to admit that atolls or barrier reefs have ever been developed after the manner indicated by Mr. Darwin's simple and beautiful theory" (1888, 262). Guppy said, in the course of a discussion of the origin of reefs, that he would "pass over the theory of subsidence because the more recent facts concerning the ocean depths and the regions of living and upraised reefs compel us to regard it as no longer necessary" (1888, 6). He also wrote: "The necessity of the explanation of subsidence has disappeared, and with it the foundation of Mr. Darwin's hypothesis" (1888, 124).

NINE VERIFICATIONS FOR SUBSIDENCE

The coral-reef problem needs a more critical treatment than it received at the hands of the authors here quoted and of many others who might be quoted to the same effect. It is therefore the object of the present paper to emphasize nine lines of verification for the theory of intermittent subsidence, some already announced, others new, which I have come to value highly while preparing a general report on my Shaler Memorial voyage across the Pacific in 1914. They contradict all still-stand theories and give Darwin's theory, in my judgment, superiority over all others. The nine lines of verification are as follows:

1. The verification of subsidence by the embayed shorelines of reef-encircled islands, long ago pointed out by Dana, has been almost universally neglected and is even now seldom applied in its full quantitative value.

2. The evidence for subsidence given by the slope of reef foundations has rarely been discussed with due regard to the physiographic evolution of reef-encircled islands.

3. The proof of subsidence that is furnished by the unconformable contact of elevated reefs with their foundation has been overlooked by most observers, and nearly all of those who have recognized the fact of unconformity have failed to see the support that it gives to Darwin's theory.

4. The proof of subsidence furnished by unconformable fringing reefs at sealevel, foreshadowed by a brief statement in Darwin's book, has never,

to the best of my knowledge, been utilized, although it is convincing when recognized.

5. The evidence for subsidence found in the peculiar distribution of submarine banks in the coral seas has never been brought forward with the emphasis that it deserves.

6. The proof of subsidence that is furnished by the disappearance of great volumes of detritus from reef-encircled islands has never been duly considered.

7. Verification of subsidence during the formation of most reefs is found in greater measure than has been generally recognized in the absence of reefs from shorelines of emergence.

8. Verification of subsidence is found in the unequal depths of lagoons and banks. And finally:

9. Evidence for intermittent subsidence is found in the form of spur ends on islands within barrier reefs. Most of these lines of verification do not apply to atolls, which are therefore briefly considered in a special section near the end of this article. The article closes with a short statement of Molengraaff's views on the isostatic subsidence of volcanic islands—a new contribution to the coral-reef problem which merits serious attention.

Embayed Shorelines

DANA'S CONFIRMATION OF DARWIN'S THEORY

Geology was not far developed when the *Beagle* made its voyage round the world, and physiography was not developed at all. Darwin wrote: "With respect to subsidence, we can not expect to find in semi-civilized countries proofs of a movement which tends to conceal its own evidence. . . . From the nature of things, it is scarcely possible to find direct proofs of subsidence" (1842, 127, 147). It was Dana, Darwin's follower in Pacific exploration, who first adduced (1849) the embayed shorelines of reef-fronted coasts in proof of subsidence. It is true that such shorelines testify strictly only to submergence, which might be caused by a universal rise of ocean level as well as by a local subsidence of the coasts concerned; but the time required in eroding the valleys of barrier-reef coasts to their pre-submergence form is so varied, and the amount of submergence demanded by the form of the embayed valleys is frequently so great, that local subsidence, varying in date and amount, gives a much better explanation of the facts as far as barrier reefs are concerned than can be given by a rise of ocean level, which must be everywhere of the same date and measure.

The most curious thing to note about Dana's argument is the manner in which it has been neglected or discredited, not only by Darwin, but by Semper, Rein, Murray, Guppy, Agassiz, Gardiner, and a host of others. Crosby, Penck, and Langenbeck are among the few who recognized the testimony of embayed shorelines in favor of Darwin's theory previous to 1900; its strength has been more generally perceived since then, but there are still many students of the old problem who overlook it; yet what can be clearer than this testimony when the attention is once directed to it! The facts have long been known. Tahaa, drawn in figure 1 as seen looking north from a summit on its neighbor, Raiatea, in the northwestern part of the Society group, justifies the account given over 80 years ago by two missionaries, who said that it is distinguished by "the number, breadth, and commodiousness of its harbors, with which the whole coast is indented, some running quite into the heart of the country." One of the harbors is sketched in figure 2, looking northwest from a point marked x in figure 1; the highest summit of the island, 1,936 feet in altitude, is indicated by three dots in both figures. Raiatea was instanced 75 years ago by Darwin as possessing "those deep arms of the sea . . . which penetrate nearly to the heart of some [reef-] encircled islands" (49). Its embayments were originally much larger than now, as is shown by the strong line drawn in figure 3 back of the present shoreline, according to my records of a two-day trip around the lagoon, to mark the junction of valley-sides with (white) delta flats. A similar map of Tahaa is given in one of my earlier articles (1916, *c,* 488). Numerous other islands have correspondingly embayed shorelines and have long been known to have them, and the correct interpretation of embayed shorelines was, as above noted, clearly stated by Dana nearly 70 years ago; yet these manifest facts and their manifest interpretation, of so critical importance in the coral-reef problem, have been ignored by most writers on the subject until recent years. This curious aspect of the coral-reef problem has been set forth in an earlier article (1913) published on the centenary of Dana's birth.

EMBAYED SHORELINES AND THE GLACIAL-CONTROL THEORY

It is not only because embayed coasts demand unlike periods of time for their erosion and unlike amounts of submergence for their embayment that they can not be explained by changes of ocean level, such as are postulated in the Glacial-control theory. The absence of partly submerged cliffs on inter-embayment spur ends that are fronted by fringing or close-set barrier reefs also contradicts an essential consequence of that theory; for the theory assumes that while the ocean was lowered and

FIGURE 1.—*Sketch of Tahaa, Society Islands*

The sketch is taken looking north from a summit at the north end of Raiatea

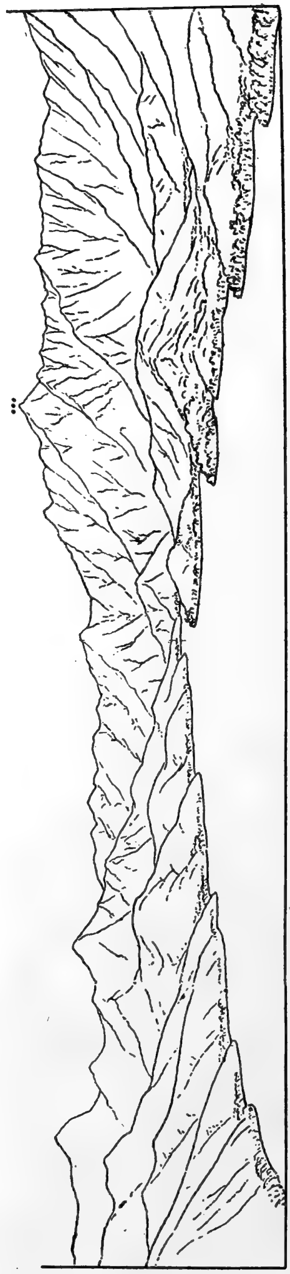

FIGURE 2.—*A Bay in Tahaa, Society Islands*

This view is drawn from the point x in figure 1

chilled in the epochs of continental glaciation, nearly all coral reefs were killed and cut away by the sea to platforms of nearly uniform depth, and that at the same time the valleys of reef-encircled oceanic islands, which

FIGURE 3.—*Original Shoreline of Raiatea, Society Islands*
The original shoreline is indicated back of the alluvial flats

are supposed under this theory to have stood still for a long period of time, were deepened by stream erosion, so that when the ocean rose to its normal level the deepened valleys were embayed; but a further consequence

of these assumed processes is, as I have elsewhere shown more in detail (1916, *c*, 563), that if the ocean were lowered for a long enough time to permit the opening of many embayed valleys to the observed width of half a mile or a mile by the slow processes of subaerial weathering under the leadership of comparatively small streams, then the powerful waves of the trade-wind seas must have in the same time cut back broad platforms and high cliffs on islands where the preglacial reefs had small breadth, and the cliffs thus cut should still be partly visible above present sealevel.

The greater rapidity of platform and cliff cutting by ocean waves than of valley deepening and widening by small streams is attested by the form of various oceanic islands, such as Tristan da Cunha, in the South Atlantic. If while the ocean was lowered small-stream valleys were so much deepened and widened that they would hold embayments half a mile or more in width after the ocean rose to its present level, the waves must have, in the same period of lower ocean level, cut a platform one or two miles wide in the same rocks; the cliffs at the back of such a platform would be 1,000 or 2,000 feet high, and hence would be still in great part visible above normal ocean level. The absence of such cliffs along the southeastern coast of Ngau, Fiji, where the present reef is a fringe about half a mile wide, and along the northeastern side of Samar, Philippines, where fringing reefs are very narrow or wanting, and along many similar coasts is strong proof that the reefs of those coasts were not killed during the Glacial period, and that abrasion did not then act as it is assumed in the Glacial-control theory to have acted.

The Slope of Reef Foundations

DEPTH OF LAGOONS AS A MEASURE OF THICKNESS OF REEFS

In view of the fact that reef-building corals can not thrive at greater depths than 25 or 30 fathoms, it has been urged by Darwin and others that barrier-reef lagoons which have a depth of 40 or more fathoms give strong evidence for the theory of subsidence. Two authors, both of whom had at one time accepted, but had later given up the subsidence theory, may be here quoted: Sir A. Geikie noted that this theory, although in general unproved, might still hold good for those reefs which inclosed lagoons 40 fathoms or more in depth (1883, 27), and Guppy wrote: "It is the depths of from 35 to 60 fathoms which are found occasionally within both barrier reefs and atolls that lend the greatest support to the theory of subsidence" (1886, 887).

THE SUBMARINE SLOPE OF REEF-ENCIRCLED ISLANDS

The above argument is good as far as it goes, but it is deficient in not taking sufficient account of the form of the coast that barrier reefs ordinarily front. Most barrier reefs encircle volcanic islands, and the islands, as a rule, exhibit maturely carved slopes of fairly strong declivity, AB, figure 4, the product of subaerial erosion, not of marine abrasion. Such slopes may be reasonably prolonged for a considerable distance below sea-level as a rough means of estimating the depth, RD, of the rock foundation beneath an offshore barrier reef, and of thus estimating the total thickness of the reef. This is especially permissible in the case of small

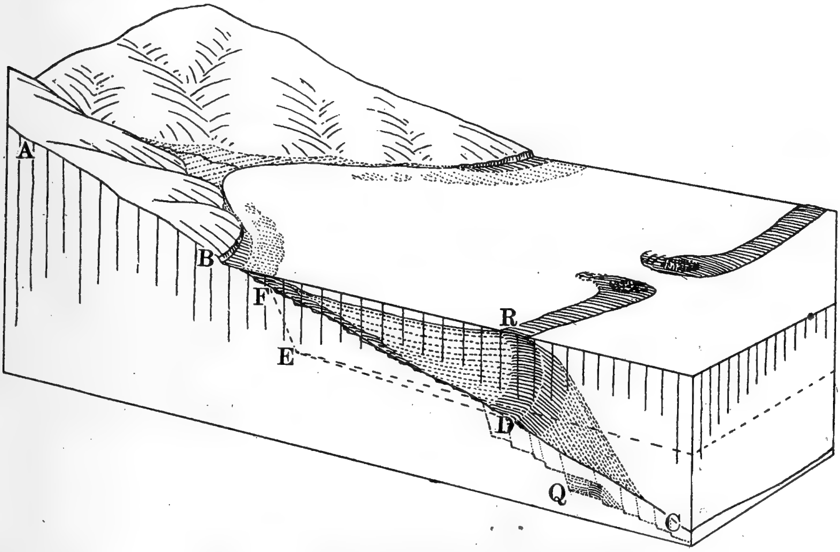

FIGURE 4.—*Submarine Slope of a Volcanic Island*

islands, like Tahaa, figure 1, that consist of single volcanic cones, more or less dissected. As the thickness thus determined may in many cases be 1,000 feet or more, it testifies much more strongly for subsidence than a lagoon depth of 40 or 60 fathoms does.

However, if it be assumed that an initial cone of resistant lavas was cloaked with a thousand feet of loosely compacted ash beds, then while the island stood a little higher than now, the ash beds might have been worn down to a lowland rim, leaving the resistant lava slopes with a relatively steep inclination; a slight submergence of such an island would provide a shallow submarine platform from which an offshore barrier reef might grow up; and the small depth of such a foundation would not be indicated by prolonging the lava slopes beneath sealevel. But there is no

reason to suppose that volcanic islands in their originally completed form usually possessed a weak ash cloak over a resistant lava core; and in the absence of such a cloak, the strong slopes now visible in dissected volcanic islands above sealevel may be reasonably supposed to extend with but small decrease of declivity to a considerable depth below sealevel.

It is also possible that a sloping platform might be produced by the offshore deposition of waste from a reef-free island, but in this case the island would be strongly clift by the unrestrained waves; and the cliffs would still be partly visible after moderate submergence. The best way of making a platform in the coral seas is in association with reef upgrowth around subsiding islands, or with reef outgrowth around still-standing islands, as Darwin supposed.

The reasonableness of the supposition that supermarine slopes may be prolonged below sealevel is increased when the depth of the sea-bottom, C, figure 4, outside of a barrier reef, R, is taken into account; it then appears more clearly than before that the reef foundation is best indicated by prolonging the visible slope, AB, of the island spurs down to the sea-bottom, C, outside of the reef. The total reef is thus seen to form a huge terrace-like mass on the submarine flanks of the volcanic cone; and the thickness of the terrace is thereby shown to be much greater than the depth of the lagoon; indeed, judging by the slopes that prevail in dissected volcanic islands, the thickness of the reef mass may usually be taken at a fifth or a quarter of the lagoon breadth: a barrier reef that stands a mile away from its encircled island may well have a thickness of 1,000 or 1,300 feet. Subsidence is manifestly necessary to produce reef upgrowth of so great a measure. But it is eminently possible that lagoons several miles in breadth, containing eccentrically placed islands, may be underlaid by an uneven surface of hills and valleys, maturely worn down on a group of volcanoes of unequal heights: here the slope of a surviving island can not be safely prolonged far from its shoreline.

In the case of barrier reefs along continental borders, the large area of land back of the shoreline will usually afford opportunity for better determination of changes of level than is provided by comparatively small volcanic islands: thus the Great Barrier reef of Australia is best interpreted by taking account of the physiographic development of the interior highlands as interpreted by Andrews (1903), from which it appears that the reef foundation probably subsided while the highlands rose, thus indicating, as I have lately shown (1917, *c*), that the coast and the adjoining sea-floor have been flexed, the coast up and the sea-floor down, and that the reef, growing up from the down-flexed area, has a great thickness. I must therefore dissent from the conclusion reached by Vaughan, that

"the width of a submerged platform [assumed to underlie a barrier-reef lagoon] bordering a land area is indicative not of the amount of submergence, but of the stage attained by planation processes" (1914, 60); for without fuller evidence that a platform on which planation processes have acted underlies a reef, this assertion is open to misapprehension, as will now be shown.

REEFS DO NOT USUALLY REST ON SHALLOW PLATFORMS

If it be urged, in opposition to the view expressed above as to the submarine extension of supermarine slopes, that marine deposition and abrasion have, with or without the aid of subsidence, fashioned a platform-like foundation for barrier reefs at a small depth, certain principles of subaerial and of marine erosion must be recalled in order to test the correctness of this view. First, reef-encircled islands are so well protected from wave attack that their form is almost wholly carved by subaerial erosion, the work of the lagoon waves being nearly negligible. Second, volcanic islands that are exposed to wave attack in the open ocean are cut back in cliffs somewhat faster than their small-stream valleys are cut down by streams and much faster than the valleys are widened by weathering; abrasion then takes place near shore, and deposition offshore. Third, the height of wave-cut cliffs on volcanic islands will ordinarily be about a quarter of the breadth of the abraded and aggraded platform from which they rise. To these three theoretical considerations, a fact of observation must be added: the spur ends of reef-encircled islands are, as already noted, rarely cut back in cliffs; when cliffs occur, they are in nearly all cases of small height and they rise from narrow rock-platforms that have been cut by lagoon waves at present sealevel.

Hence, if a barrier reef be supposed to have grown up from the outer margin of an abraded and aggraded platform, the spur ends of the island should, as above noted, be cut off in cliffs having a height equal to about a quarter of the lagoon breadth, and the cliffs should still be partly visible after moderate submergence; but such cliffs are almost unknown. If a platform has really been abraded it must have been strongly submerged by subsidence since it was abraded, in order that the spur-end cliffs back of it shall no longer be visible; the measure of the subsidence must be about a quarter of the lagoon breadth at least. It thus appears probable that, even if abrasion produced a platform before reef growth began (as will be later shown to be probable), the thickness of the reef built up on the platform margin must be much greater than the depth of the aggraded lagoon that it incloses; and reef growth must therefore have been accompanied by a rather strong subsidence of the reef foundation.

Reference may be made here to other statements by Vaughan, as sequels to the one quoted above; they are to the effect that "many, if not all, barrier reefs stand on marginal platforms [corrected by the author to read "stand on or margin platforms"] which already existed previous to Recent submergence and the formation of the modern reefs" (1914, *a*, 59); and that "a study of the charts of barrier-reef islands, as Viti Levu, Fijis, and Tahiti, Society Islands, shows that the platforms are independent of the presence of reefs, and therefore the relations in these islands are similar to those indicated for barriers off continental shores, for here the reefs are also superimposed on platforms antedating their presence" (1914, *b*, 33). As far as I can penetrate the problem, these inferences are not borne out by the facts.

It is probable enough that pauses in the submergence of a reef, such as could be caused by the coincidence of slow subsidence and the slow lowering of the ocean surface during the oncoming of a Glacial epoch, might have caused a previously narrow barrier reef to widen greatly while its lagoon was nearly or quite filled up with detritus, so that the reef and lagoon together came to form what may be called a mature reef plain. It is also possible enough that during a rapid submergence, such as might be caused by the coincidence of slow subsidence with the slow rising of the ocean surface during the passing of a Glacial epoch, might cause a relatively narrow barrier reef to grow up on or near the margin of a previously formed, mature reef plain, and more or less completely encircle it. But the implication of the above quotation is that the platforms there mentioned are not of coral-reef origin; and this is confirmed by the explicit statements regarding many reef-bordered lands, to the effect that "the platforms have an existence independent of coral reefs and were formed by other than coral-reef agencies," and that "an inspection of the Admiralty charts for the eastern coast of Australia shows conclusively that the platform on which the Great Barrier reef of Australia stands has an existence independent of the Great Barrier reef" (1914, 33, 32).

FACTS AND INFERENCES FROM CHARTS

Vaughan's opinions regarding reefs in the Pacific are, as the above quotations show, based not on local observation, but on a study of hydrographic charts, and such charts do not give enough information—apart from the occurrence of embayments—regarding the physiographic development of reef-bordered coasts to lead to safe conclusions. It has been well said that "the principal value of the coral-reef investigation to geology consists not so much in what has been found out about corals as in the study of a complex of geological phenomena, among which coral reefs

are only a conspicuous incident": and it may be added that the shore outlines and offshore soundings given on hydrographic charts do not suffice for the satisfactory study of such a complex. The flat floor of a barrier-reef lagoon is well shown on charts, but it should not be thereupon assumed to represent a platform produced by other than reef-making agencies, for the floor is aggraded by an unknown thickness of detritus on a foundation of unobservable form.

Again, the change from a gentle slope to a steep pitch at a depth of about 40 fathoms is a persistent feature in the exterior profile of many reefs, but it is less satisfactorily explained as the edge of an antecedent platform made independently of reef formation than as a miniature continental shelf made by the action of marine agencies on reef detritus with respect to present sealevel; for, as Daly has pointed out, "the break of slope" on continental shelves formed by wave and current action is "near the 40-fathom line" (1915, 199). Likewise, the change at about 40 fathoms depth from a nearly flat floor to a steep pitch where a lagoon is not completely inclosed by a reef, or where a reef stands back from an exterior bench margin, finds competent explanation by marine aggradation of an earlier reef or reef-plain with respect to present sealevel, and should not be taken to indicate the existence of a platform at that depth, formed independently of reef-making agencies. I have treated this aspect of the coral-reef problem more fully in an article on "Coral reefs and submarine banks" (1918, *a*).

THE EVIDENCE OF VITI LEVU, TAHITI, AND QUEENSLAND

Viti Levu (Fiji), Tahiti, and Queensland (northeastern Australia), associated in the above quotations from Vaughan's essays as if their reefs had all been formed under similar conditions, are found to have really had very different histories, when the coasts back of the reefs as well as the charts of the reefs are studied. The present barrier reef of Viti Levu has, I believe, been formed by upgrowth on the more or less aggraded borders of a greatly eroded volcanic mass of complicated history, during a slightly unequal subsidence, of greater measure on the northwest than on the south; there is no sufficient reason for thinking that a flat platform, formed independently of coral-reef agencies, serves as its foundation, as will be further shown below. The French island of Tahiti is a submaturely dissected volcanic island that has truly had a platform a mile or two wide, backed by cliffs 1,000 or 2,000 feet in height, abraded around its shores; the proof of this statement is, however, not found in the soundings recorded on charts, but in the cliffs observed around the island border, of which the charts give no proper indication and of which

Agassiz alone has given an adequate description. The barrier reef of Tahiti surmounts the margin of the abraded platform, now submerged to a depth of a hundred fathoms or more, as I have shown in detail in an article to be published in the *Annales de Géographie* during 1918; but no other member of the Society Islands is similarly cut back in sea-cliffs, and hence no other reef in that group rests on a submerged abraded platform—unless, as will be shown on a later page to be eminently possible, the submergence of the platforms has been so great as completely to drown the cliffs that must have risen to heights of 1,000 feet or more from their inner margin; and platforms so greatly submerged have no close relation to the shallow platforms inferred by Vaughan, which are supposed to lie about 40 fathoms below present sealevel.

According to the best application that I could make of Andrews' physiographic studies of eastern Australia during my journey there in August, 1914, the Great Barrier reef of the Queensland coast has been formed by upgrowth during the long continued but intermittent down-warping of the continental margin; and the conditions for reef growth during the earlier stages of down-warping appear to have been just as good as they are today. The total thickness of this vast reef may well be thousands rather than hundreds of feet. The present reef is more probably constructed on or near the margin of a preexistent, mature reef plain than any other reef that I have seen, as I have shown elsewhere in some detail (1917, *c*). Thus the reefs of Viti Levu, Tahiti, and northeastern Australia have been formed under diverse conditions that do not by any means support Vaughan's conclusions. All of these reefs owe their opportunity of upgrowth to the subsidence of their foundations, whatever the previous form of the foundations may have been.

DETAILS CONCERNING FIJI REEFS

As my acquaintance with the reefs of the Fiji Islands is more extended than with those of most of the other groups that I visited in 1914, it is particularly with respect to the Fiji reefs that I must take exception to Vaughan's opinion, quoted above, that they are "superimposed on platforms antedating their presence"; and especially to his later statement to the effect that "Andrews has essentially confirmed" this opinion (1916, 133). There is nothing in Andrews' recent article on Fiji to warrant such an assertion; his brief summary regarding the largest island of the group is that its "present great barrier reef, which rises to the level of the sea, has thus, in all probability, been built up by coral-reef organisms on the submerged lowlands of Viti Levu" (1916, 138); but the lowlands that are submerged along the southern border of the island, where An-

drews observed them over 17 years ago, consist of the maturely dissected strata of a slanting marine coastal plain, as will be further explained in a later paragraph; and as such they constitute a moderate submarine slope of rather uneven surface, but not a "platform" in any proper sense of the word. As to the northwestern side of the island, where the barrier reef incloses an exceptionally broad lagoon interspersed with volcanic islands, no one knows what the shape of the reef foundation is; its outer part is imperfectly charted. The only geological observer who has lately visited that district is Foye, who writes: "In general the present coral reefs [of Viti Levu] are developing on platforms which originated during the deposition of the coastal series" (1917, 306); but the word "platform" is here used in a very general sense, inasmuch as it applies to the uneven surface of the formerly uplifted, then dissected, and now submerged coastal plain on the south, as well as to the extensive lagoon area of the northwest, regarding the foundation of which no details are at hand.

All the facts that I noted in Fiji confirm the opinion that the barrier reefs of those islands have grown up from submerged insular slopes, whatever form the slopes happened to have when they were submerged. They were presumably less inclined beneath the broad lagoon northwest of Viti Levu than beneath the narrow lagoon on the south; the same statement may apply to the second largest island of Vanua Levu. The larger the land area concerned, the larger its rivers and the better the opportunity for the formation of sloping offshore deposits, to which the term, "platform," may perhaps apply: it is probably for this reason that the two largest islands of Fiji lend some color of support to Vaughan's view. The submerged slopes are pretty surely of moderate inclination around the small Exploring Isles also, for there a worn-down barrier reef of earlier origin, now submerged, appears to furnish the foundation for the present barrier reef; but the earlier reef was formed on a strong volcanic slope (1916, *b*). Around all the other Fiji Islands that I saw—Mbengha, Kandavu, Ono, Matuku, Totoya, Moala, Ngau, Ovalau, Nairai, Makongai, Wakaya, Rambe, and a few more, all smaller than the two larger ones—there is no indication that the submerged volcanic slopes were significantly less steep than the strongly inclined visible slopes. I must therefore conclude that submerged platforms "formed by other than coral-reef agencies" are unessential to the formation of barrier reefs in Fiji.

NEGLECT OF PHYSIOGRAPHIC EVIDENCE

A paragraph may be given to inquiring why considerations so manifest as those presented above regarding the submarine slope and other features

of reef-encircled islands have not ordinarily been given greater weight by students of the coral-reef problem in the Pacific. As far as I can judge, after an extended review of many articles on the subject, the answer to this inquiry is that both the inductive and the deductive sides of the problem have generally been neglected, in so far as they concerned the physiographic features of reef-bordered coasts. The deductive phase of physiographic investigation in particular has been overlooked: how can the prevalent inattention to the embayments of reef-encircled islands be explained otherwise! A simple matter of observational record, such as the depth of a lagoon, is treated with due respect; but the equally pertinent matter of physiographic inference touching the submarine prolongation of an island slope has usually been mistrusted or disregarded by the objectors to Darwin's theory. Of course, an inference of this kind is not so well assured as an observed fact; but when it comes to estimating the thickness of barrier reefs and the conditions and processes of their formation, not only every recorded fact, but every pertinent inference, such as that above presented concerning the relation of supermarine and submarine slopes, should be given due weight.

Unconformable Elevated Reefs

NEGLECT OF GEOLOGICAL EVIDENCE

Since the contact of reef limestones on their foundation of volcanic rocks is a geological rather than a physiographic matter, it may be said that the geological as well as the physiographic aspects of the coral-reef problem have been too generally neglected; for the prevailingly unconformable nature of reef-limestone contacts is discovered by observation of reef-encircled islands as easily as the prevailing inattention to the nature of such contacts is discovered by inspection of standard works and articles on the coral-reef problem. It would not seem to require a lofty flight of scientific imagination to deduce the unlike consequences as to reef-limestone contacts that are involved in the theories of outgrowing reefs, as shown in sectors A, B, C, figure 5, on still-standing, down-wearing volcanic islands, and of upgrowing reefs, as shown in sectors X, Y, Z, on intermittently down-sinking volcanic islands. In the first case, if the reefs are not smothered by outwashed detritus, as will be shown on a later page to be probable, all the reef limestones must lie conformably, as is shown in the section of sector B, on a non-eroded submarine slope of constructional origin. In the second case, all the limestones that are deposited, as the island subsides, above the level of the original reef attachment must lie, as is shown in the section of sector Y, more or less

unconformably on a sloping surface of subaerial erosion, perhaps clift at the base; only the exterior talus deposits can lie conformably on a non-eroded volcanic slope, and even these may, in certain cases noted below, lie unconformably on a slope of subaerial erosion.

UNCONFORMABLE ELEVATED REEFS IN FIJI

Furthermore, it would not seem to require a very penetrating use of scientific observation to determine which one of these contrasted consequences is confirmed by the facts. Elevated reefs in particular should offer excellent opportunity for applying so crucial a test, and, as will appear below, their unconformable contacts have truly enough been noted in a fair number of cases; but unhappily this important matter has ordinarily been overlooked, and even when noted the consequences following from it have not usually been correctly inferred. One of the best examples of the kind that has come to my own attention, and of which I have already given a brief account (1915, 250), is found on Vanua Mbalavu, one of the Exploring Isles that are inclosed in a great barrier reef, 23 miles in longest diameter, in the eastern part of the Fiji group. Here the largest volcanic island, 13 miles in length, partly shown in figure 6, has a maturely carved form, and rises to an altitude of 930 feet; it is in part unconformably covered up to heights of 500 or 600 feet, as shown diagrammatically in sector E, by a deeply dissected and well embayed mass of limestone, which is therefore probably, as Agassiz said, the "fragmentary remains of the land which must have once occupied the area of the lagoon," now inclosed by the great barrier reef.

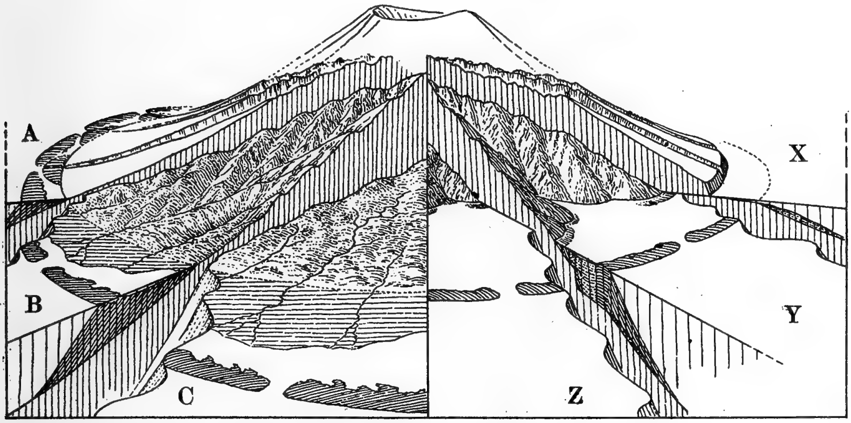

FIGURE 5.—*Contrasted Consequences of Murray's and Darwin's Theories*

The surface of unconformable contact has about the same slope as the uncovered spurs; it dips under sealevel to an unknown depth, x, as shown in the section within sector E: hence the volcanic island must have formerly stood, while suffering erosion before the limestones were formed, x feet higher than now, as in sector A. The limestones are much eroded and their upper surface must once have been y feet higher than now. Hence after the island had been maturely eroded it must have subsided $(x + 600 + y)$ feet while receiving the unconformable limestone cover, which presumably assumed the form of an almost-atoll, sector B—that is, a barrier-reef mass in which only a very small central island $930 - (600 + y)$ feet high survived. As the present limestone remnants are greatly reduced from their initial form, whatever that form was, it is

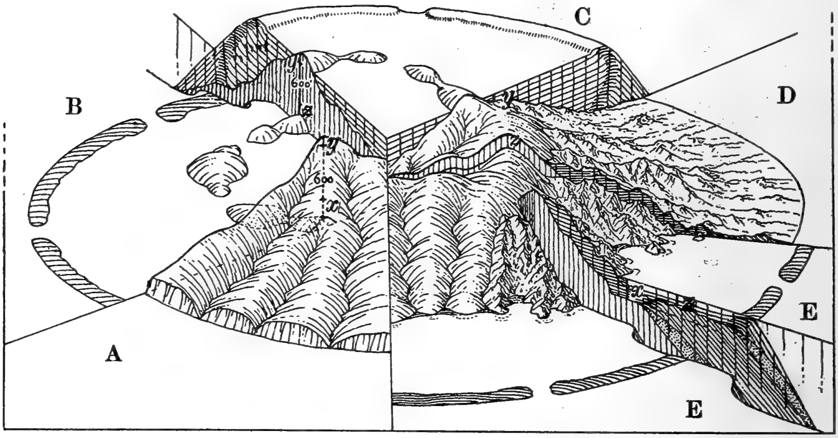

FIGURE 6.—*Evolution of Vanua Mbalavu, Fiji*

manifestly only as an inference that the initial form is here described as a "barrier-reef mass"; but that inference appears to me a very reasonable one, in view of all the elements of the case. Had the original limestone mass accumulated as a shoal or submarine platform, 30 or 40 fathoms deep, bearing patches of coral here and there but not inclosed by a marginal coral reef, the volcanic island that rose from the shoal would have been clift; but the volcanic island, where the limestone remnant lies unconformably on it, as in sector E, has a moderate slope: hence the limestones were probably accumulated as part of a great barrier-reef and lagoon mass, as above stated. Had the central island of such a shoal been protected by fringing reefs, it would not have been clift, but the altitude of the fringing reefs above the general surface of the shoal would demand a greater subsidence than is here assumed.

The present remnant of the limestone mass, where it has not been wholly stripped from its volcanic core, has an embayed shoreline, indicating a recent submergence of z feet; hence, after the formation of the limestones, the compound island must have been elevated by $(y + 600 + z)$ feet, as in sector C, and long exposed to erosion, as in sector D. The elevation as well as the preceding subsidence need not have been precisely uniform; both may have included a moderate tilting such as will be shown below to have accompanied a following subrecent subsidence. It was during this subrecent subsidence, after the island had stood z feet higher than today, that the present barrier reef shown in sector E must have grown up.

The present lagoon, the floor of which is more or less aggraded, is only 20 fathoms deep on its western side, but slants down to a depth of 80 or 90 fathoms on its eastern side, as Agassiz pointed out; hence the measure, z, of recent submergence is a variable quantity, and the submergence could not have been due only to the postglacial rise of ocean level, but must have involved a slanting subsidence which, where greatest, appears to have been about 600 feet. Moreover, the subsidence must have been relatively local, for 30 miles to the southwest the undissected and therefore recently elevated atoll of Vatu Vará rises to a height of 1,030 feet. I have employed the evidence of local elevation and subsidence furnished by Vanua Mbalavu to determine the conditions of origin of several small near-by atolls (1916, *b*), and believe that thus, for the first time, fairly direct proof has been provided for the upgrowth of atolls during subsidence.

Although good evidence of repeated changes in level and of reef-limestone formation during times of subsidence seems to be furnished by Vanua Mbalavu, there is no reason for believing that this interesting island is an exceptionally favorable illustration of Darwin's theory. My reason for visiting it was not that its history was thought to be more significant than that of other islands in Fiji, but simply that it was on the route of a small trading steamer: a hurricane happened along as we arrived there, and refuge was taken for two nights and a day in one of the limestone embayments; the volcanic part of the island was seen on the following day of fine weather, after which another limestone embayment was entered for a night. In the first embayment the limestones were seen to be horizontally stratified, as shown in section in the middle of sector E, figure 6.

The geological history above inferred for the island has been confirmed by Foye's more detailed observations (1917). Other islands may well have an equally suggestive story to tell; thus the volcanic island of

Lakemba, somewhat farther south, has been lately interpreted by Foye as having been first maturely eroded, then submerged 320 feet or more and bordered by an unconformable cover of coral limestone, and finally elevated with a tilt to the east (1917, *b*, 348). And yet, simply because uplifted limestones occur on various members of the Fiji group, these islands have been said to occupy a "region of elevation"; and, no attention being paid to the unconformable contact of the elevated limestones with their volcanic foundations or to the embayed shorelines of the volcanic and limestone islands, subsidence has been excluded from the conditions of reef-making around them.

ELEVATED REEFS MAY HAVE BEEN FORMED DURING SUBSIDENCE

Elevated reefs have often been treated by observers who took no account of unconformable contacts, as if the reef had been formed during pauses

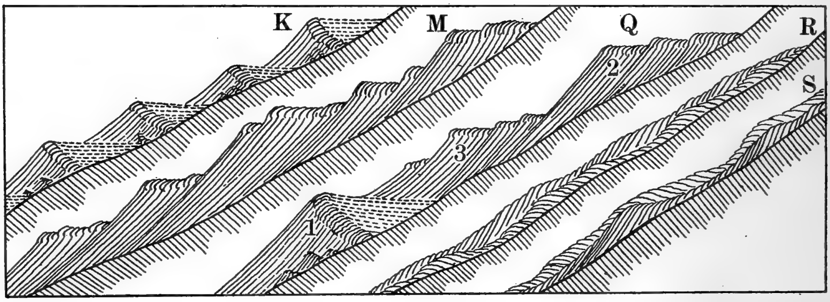

FIGURE 7.—*Inferred Structure of Reefs formed during Submergence and Emergence*

in the elevation of their foundation, and as therefore invalidating Darwin's theory. Yet it should be manifest, as soon as the unconformity with their foundation is recognized, that submergence must have taken place before emergence, and hence that such reefs are reasonably explained either as formed during pauses in submergence, followed by an emergence too rapid for reef growth, or as formed during pauses in emergence preceded by a submergence too rapid for reef growth. Safe choice between these evident alternatives can be made only by detailed observational studies of reef structures, which, as is always the case in such problems, are much facilitated if the theoretical possibilities are carefully deduced while or before observation is in progress.

For example, section K, figure 7, illustrates the expectable relations of a series of unconformable reefs formed in ascending order during intermittent subsidence; section M shows the expectable relations of a series of reefs formed in descending order during intermittent upheaval; sec-

tion O shows reef 1 formed during a movement of subsidence, which is then continued so rapidly that no other reef is formed until, after a pause, upheaval sets in; reefs 2 and 3 are thus formed above reef 1. Continuous submergence followed by a similar emergence might produce such a structure as section R; continuous emergence followed by similar submergence might result in a structure like section S. It is easy enough to deduce these and other expectable conditions; it is a difficult matter to apply them in the examination of uplifted reefs, where clear sections are rarely exposed; but the difficulty of examination is certainly lessened if the critical points are thought out beforehand.

The numerous elevated fringing reefs of the New Hebrides seemed to offer good opportunity for detecting their structure; a few of them on the island of Efate were therefore examined, in company with E. C. Andrews of Sydney, on my journey of 1914, with the problem as here stated in mind. The results gained will be set forth in my final report; while not conclusive, they gave much reason for thinking that the reefs are unconformable, and that some of them at least were formed during the subsidence of their foundation previous to the later movement of elevation.

ACCOUNTS OF UNCONFORMABLE REEF CONTACTS

It is not, however, only in Darwin's writings that the unconformable contact of reef limestones with their foundations is overlooked, both as a manifest fact of occurrence and as an inevitable consequence of the theory of subsidence. Nearly all other writers on the coral-reef problem have past over this significant structural matter in silence. Among the few who have mentioned it are Richthofen, who many years ago explained an uplifted reef on the south coast of Java, 40 feet above sealevel, as a barrier reef that had been built during subsidence on the worn edges of horizontal Tertiary strata (1874, 246); Walther, who explicitly recognized the importance of unconformable contacts as proving subsidence, in his study of uplifted coral reefs in the Red Sea (1888); Lister, who described the unconformable contact of elevated reef limestones on their foundation in the island of Eua, a small southeastern member of the Tonga group (1891); Brouwer, who describes Roti, a small continental island near Timor, in the East Indies, as composed of deformed strata, unconformably covered with terraced limestones which form the greatest heights (214 meters); hence this island is an elevated atoll with visible, nonvolcanic, unconformable foundation (1914); and Molengraaff, who has described unconformable elevated reefs in the small island of Letti, in the same region (1915).

PREVAILING INATTENTION TO REEF CONTACTS

Various other writers on the islands of the Australasian archipelago have noted the unconformable contacts of elevated reef limestones with the underlying rocks, but few of these writers have emphasized the bearing of such contacts on Darwin's theory of coral reefs, and the majority of writers on elevated reefs have paid no attention to the nature of the reef contacts. The unconformity of sealevel reefs, to be considered below, appears to have been even more generally overlooked. Indeed, unconformable reef contacts, like embayed shorelines, have no generally recognized place in the discussion of the coral-reef problem in standard text-books. These two fundamental principles are, with three exceptions noted below regarding embayed shorelines, not mentioned in the discussion of coral reefs in Bonney's Story of our Planet (1893), Credner's Elemente der Geologie (1897), Green's Physical Geology (1882), Geikie's Text-book of Geology (1893), Günther's Lehrbuch der Geophysik (1885), Hahn's Inselstudien (1883), Hann, Hochstetter and Pokorny's Allgemeine Erdkunde (1881), Haug's Traité de Géologie (1907), Jukes-Brown's Handbook of Physical Geology (1892), Kayser's Lehrbuch der allgemeinen Geologie (1893), Lake's Physical Geography (1915; embayments are briefly mentioned), de Lapparent's Traité de Géologie (1906), Leconte's Elements of Geology (1895), Lyell's Principles of Geology (1872), de Martonne's Traité de Géographie Physique (1909), Neumayr's Erdgeschichte (1886), Penck's Morphologie der Erdoberfläche (1894; embayments are briefly considered), Peschel-Leipoldt's Physische Erdkunde (1879), Pirsson and Schuchert's Text-book of Geology (1915; embayments are briefly mentioned), Prestwich's Geology (1886), Phillip's Manual of Geology (1885), Richthofen's Führer für Forschungsreisende (1886), Scott's Introduction to Geology (1897), Suess' Antlitz der Erde (volume ii, 1888), Supan's Grundzüge der physischen Erdkunde (1896), Tarr and Martin's College Physiography (1914), Toulet's L'Ocean (1904), Wagner's Lehrbuch der Geographie (1908), or Walther's Allgemeine Meereskunde (1893) and Einleitung in die Geologie (1893).

In view of such neglect of essentials, it is not too much to say that the treatment of the coral-reef problem in our text-books is in serious need of critical revision.

Unconformable Fringing Reefs

MANY FRINGING REEFS TESTIFY TO SUBSIDENCE

The evidence of unconformity, frequently detected in studies of elevated reefs, may be found about as easily in the case of sealevel fringing

reefs, whether they front the open ocean, as will be shown to be usually the case in the Philippine Islands, or lie along the shore of a lagoon inclosed by a barrier reef, as commonly happens in the Fiji and Society Islands. For the maturely carved spur ends of the embayed shorelines around which fringing reefs, whether standing alone or inside of barrier reefs, are ordinarily formed, as shown in figure 8, have manifestly been much modified by subaerial erosion from the initial slopes of a young volcanic cone: truly not so much modified in quantity as the inter-spur valleys, but as plainly modified in quality. Reef contacts around such spur ends are evidently unconformable and therefore testify to submergence.

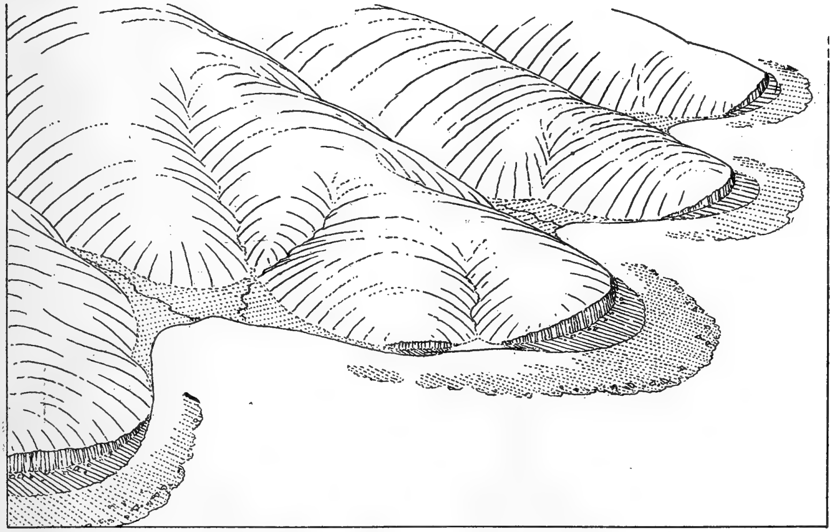

FIGURE 8.—*Unconformable Contact of a sealevel fringing Reef on the Spurs of a dissected volcanic Island*

It is not simply that fringing reefs testify unqualifiedly in favor of unconformable contacts, and therefore in favor of submergence, in practically every case where the inquiry thus suggested has been made; they also testify in many cases to a pre-submergence erosion of so great an amount and therefore of so long a duration, and also to a submergence of so great a measure, that the submergence can be fully explained only by the aid of subsidence and not alone by the rise of ocean level at the end of the Glacial period. Unconformable contacts involving moderate measures of erosion and of submergence might be developed on still-standing islands as a result of the moderate lowering of the ocean during the several moderate time intervals of the Glacial epochs; but the great

unconformities of certain slightly elevated fringing reefs on the profoundly eroded older (western) volcanic mass in the Oahu doublet, of the fringing reefs in the lagoon of the barrier reef that surrounds the skeleton island of Borabora in the Society group, and of the fringing reefs along the greatly degraded lowlands along the southwestern side of New Caledonia and along the Queensland coast inside of the Great Barrier reef of Australia—these and many other similar unconformities stand incontestably for Darwin's theory.

DARWIN ON FRINGING REEFS

The testimony of fringing reefs thus appears to be in most cases the very opposite of that usually credited to them. It has been noted above

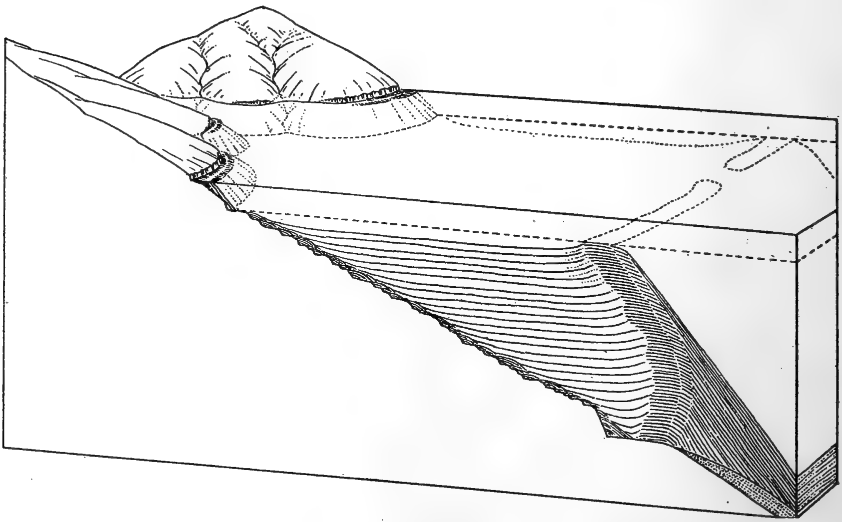

FIGURE 9.—*Submerged barrier Reef and a fringing Reef of a new Generation*

that Darwin regarded most fringing reefs as formed on rising coasts; it is not generally understood that he also perceived that they might be formed on subsiding coasts, where the subsidence has been so rapid and so great as to drown any preexistent reefs. The statement of the young naturalist on this point is brief but explicit: "If during the prolonged subsidence of a shore, coral reefs grew for the first time on it, or if an old barrier reef were destroyed and submerged, and new reefs became attached to the land, these would necessarily at first belong to the fringing class" (1842, 124). It is to be regretted that this passage has not been more frequently quoted. The point of it has been independently stated by Chantérac (1875, 635), but by no other author I have read.

Fringing reefs thus formed may be described as of a new generation. The dimensions of the embayments of the shore that they border may indicate a greater submergence than would be inferred from the small advance of the reefs from the shore; and this I found to be the case on certain members of the New Hebrides group. The external talus of such reefs as well as the reef proper may rest unconformably on a slope of subaerial erosion, now submerged: they may be frequently associated with drowned fringing or barrier reefs of earlier origin, as indicated in figure 9. Unfortunately reefs of this kind received no further attention from Darwin than the above statement, apparently because the records available to him showed the frequent occurrence of elevated reefs or of marine fossils on the slopes above fringing reefs and thus led him to associate such reefs with areas of elevation; but also because he did not perceive that when fringing reefs lie unconformably on a surface of subaerial erosion, as reefs of a new generation must, submergence should have preceded or accompanied their formation, even if the submergence had been preceded by elevation. Unfortunately, also, many other students of coral reefs have overlooked the occurrence and the significance of the structural relations between sealevel fringing reefs and their foundation, as here indicated.

FRINGING REEFS OF THE PHILIPPINE ISLANDS

Unconformable fringing reefs of a new generation appear to characterize the shores of the Philippine Islands to a remarkable degree, while barrier reefs and atolls are rare thereabouts, as may be learned from the admirable charts recently issued by our Coast and Geodetic Survey; and yet no one has, so far as I have read, perceived that the facts thus presented afford strong testimony for Darwin's theory of subsidence. The manifestly unconformable contacts of the fringing reefs on the maturely dissected and more or less embayed shores of many members of the much disturbed Philippine group, largely formed of non-volcanic rocks, demand long continued erosion while the islands stood higher—in several cases much higher—than now, and a correspondingly great, though by no means uniform or universal, subsidence to bring them down to their present position; and this at so rapid a rate that preexistent reefs, if they existed, were drowned, and at so recent a time that the fringing reefs on the headlands and the deltas in the bay heads have not as a rule attained great development. The west coast of Palawan, the southwesternmost member of the Philippines, gives many striking illustrations of these features, none more impressive than at Malampaya Sound, here shown in figure 10, reduced from a part of Coast Survey chart 4316. Joubin's

FIGURE 10.—*Malampaya Sound, Palawan, Philippine Islands*
From Coast Survey chart 4316

chart of coral reefs (1912) gives the fringes of the Philippines a much greater breadth than they usually possess.

The existence of earlier formed reefs at lower levels, now drowned, is highly probable on many of the Philippine Islands; for the absence of strong cliffs on the headlands of their embayed shores indicates the presence of protecting reefs while the coasts were suffering erosion before their recent subsidence; thus all the more does the absence of an extensive system of offshore barrier reefs, which should have grown up from the preexistent reefs during a slow subsidence, indicate that subsidence was more rapid than reef upgrowth. Moreover, the submarine platforms that border some of the islands are best explained as submerged and more or less aggraded reef plains, on the outer margin of which new barrier reefs have failed to reach the present surface because of rapid and recent subsidence; indeed, some of the platforms have no sign of upgrowing marginal reefs, and these must have been submerged with unusual rapidity at a very recent date. It is quite possible that some of the shorelines here treated as showing recent submergence may have afterwards emerged by a moderate amount from a previous greater submergence of moderate duration, for charts do not always suffice to distinguish between these two cases; but in either case, the fringing reefs would rest unconformably on their foundations.

The facts here discovered seem to me to give strong confirmation to Darwin's views; not only so, they show that, after the many other movements the Philippines have suffered, the recent subsidence of many of the islands has been more rapid than reef upgrowth, and hence more rapid than the subsidence of most of the islands in the central Pacific around which barrier reefs or above which atolls are commonly found. In this respect I believe the recent history of the Philippines to be representative of that of the other archipelagoes of the western Pacific, where, in spite of the evidence for submergence given by strongly embayed shorelines, barrier reefs are imperfectly developed and atolls are rare.

The smaller islands of the archipelagoes, although often possessing embayed shorelines, are not as a rule encircled by well developed barrier reefs, such as those which characteristically surround the islands of the Fiji and the Society groups. No such extensive barriers as those of New Caledonia and the Queensland coast of Australia are known around the larger islands of the archipelagoes today. Nowhere are the larger islands bordered at present with barrier reefs at all comparable to the barrier which, when certain islands stood higher in the recent past, fronted the northwest coast of Palawan for 300 miles, as further stated below; nowhere at present is there an atoll or almost-atoll comparable to the

exceptionally long one which, when certain islands stood lower, crowned the long ridge of Cebú where, according to Becker, a mantle of coral reaches "to the very crest of the island. . . . 2,362 feet in elevation" and gives it "an even line many miles in length" (1901, 69, 75).

The occurrence of elevated reefs, probably fringes or barriers, has been recorded on many other islands of the Australasian archipelagoes; Semper found what he took to be an elevated atoll at an altitude of more than 3,000 feet on Luzon, and Drasche found reef limestones on the same island at altitudes of 3,500 and 4,000 feet (1871, 31-, 42-); but these and other earlier authors do not state whether the limestones rest conformably or unconformably on their foundation. This critical matter is later touched on by Becker and Smith, though without full application of its meaning. Becker states that the Philippines suffered deformation and uplift in late Eocene time, that they sank in late Miocene time, and that general upheaval with oscillations has taken place since. "All the evidence thus far adduced, both paleontological and structural, points to a progressive uplift of the archipelago, beginning in the late Miocene and still proceeding. . . . Evidences that the islands are rising at the present time, or have been rising within a few years, abound from one end of the group to the other. It is also clear that the amplitude of the movement has been very great" (1901, 79, 77).

Furthermore, Becker notes that Cebú in particular is covered for the most part by a mantle of coral, 100 or more feet in thickness, which reaches from the crest of the island to the sea and forms "a vast number of terraces, all of which are sensibly horizontal" (1901, 19, 79), while in Negros there is "a series of hills flanking the main range with excessively steep slopes and crests only a few feet in width. They were composed of rough coral and seemed to represent barrier reefs" (75). The same observer states explicitly that there is a "great unconformity both in Cebú and in Negros. It lies between the [Miocene] lignitic series and the coral mantle" (69), but he inclines to believe that the elevated reefs of these islands were formed during the elevation of their foundations and not during the preceding subsidence; and perhaps for this reason he gives some credence to Semper's objections to Darwin's theory.

W. D. Smith, whose latest paper on the Philippines makes reference to "coral platforms" (fringing reefs) on which the outwash of alluvium is rapidly forming coastal plains, notes that "in a few places the reefs were found to make an unconformable contact with eroded igneous rocks beneath" (1917, 540), but no inference is drawn from this as to rapid subsidence preceding the formation of the present reefs, presumably because the origin of reefs was not the special subject of study of this

observer. It is probably because of the great extent of the Philippines and the complications of their history that neither Becker nor Smith is very explicit regarding the physiographic aspects of the development of the archipelago. For example, Smith states: "There undoubtedly has been a general subsidence at times of the whole archipelago," and "a corresponding and a very general elevation" (521); but it is not clear from the context what form the islands had when these movements took place, and without an understanding of that physiographic element the progress of events is not clear.

The best inferences that I can make lead me to think that oscillations of large value, varying from place to place, have been added to the simple scheme of a Miocene submergence and a later emergence of the whole group; for Pliocene, Pleistocene, and Recent time are long enough for many changes of level, as well as for much erosion and deposition during such changes. The sharp irregularities of the shorelines of many islands can hardly be explained by a simple three-phase scheme of (1) Eocene deformation and uplift, with the addition of erosion that is implied but not physiographically expressed; (2) Miocene depression, with the deposition of reef limestones as well as of sediments, which should be abundant in a mountainous and rainy archipelago, and which should cover over and soften the submerged surfaces of subaerial erosion, but of which little is said; and (3) post-Miocene elevation, with reef growth during pauses. It therefore seems legitimate to expand this simple scheme by the addition of later and more or less recent oscillations, and in connection with the coral-reef problem to give special emphasis to the recent movements of depression that are attested by the submerged platforms, the minutely irregular shorelines, and the narrow fringing reefs of certain islands.

This conclusion is fully borne out by studies of other archipelagoes, where reef limestones occur at altitudes of 1,000 or 2,000 feet and where Pliocene and Pleistocene deposits are frequently deformed; and from all this it must be inferred that upheavals as well as subsidences of various measures have been much stronger and more frequent in the Australasian archipelago than in the central Pacific, east of Fiji and Tonga, where elevated reefs are comparatively low and rare. The archipelagoes thus appear to be the seat of active and diverse movements of subsidence and upheaval, while the central Pacific is characterized by relatively slow subsidence. Return will be made to this subject on a later page.

THE PHILIPPINES AND THE GLACIAL-CONTROL THEORY

The discontinuous reefs of the Philippines not only support the explanation given by Darwin for fringing reefs of a new generation, but also

provide strong testimony against certain essential features of the Glacial-control theory, which is today the only serious competitor of the theory of subsidence. All other modern theories, of which I have elsewhere given a somewhat detailed review (1914), are discredited by their neglect of the submergence that is demanded by embayments and unconformities. The principles involved in the Glacial-control theory were briefly stated in an earlier paragraph, but will now be considered more deliberately.

According to the Glacial-control theory, which assumes reef-encircled islands to be stationary as a rule, there might have been narrow preglacial fringing reefs on the Philippine Islands where the shores pitch down steeply into deep water; and if the corals on the exterior slopes of such reefs were killed by the cooled waters of the lowered Glacial ocean, the reefs should have been cut away by the waves. Now if the abrasion then operative endured long enough to cut down the large hypothetical, still-standing volcanic island in the center of the China Sea, at present represented by the Macclesfield bank, which measures 95 by 35 nautical miles, as is also assumed by the Glacial-control theory, then a comparatively broad platform backed by strong cliffs should have been abraded on all the exposed island slopes of the Philippines; and when the ocean rose to its normal level again in postglacial time, a barrier reef should have grown up on the outer margin of the abraded platform, and the tops of the cliffs should still be visible above sealevel.

On the other hand and as a matter of fact, barrier reefs and high shore cliffs with submerged bases are hardly known in the Philippines. Submarine platforms of various breadths up to 30 miles, and at various depths from 20 to 60 fathoms, are truly enough found bordering some of the islands, but the island shores are nevertheless characterized by unclift promontories, sometimes without reefs, as along the mid-west coast of Palawan, figure 10, but usually margined with unconformable fringing reefs from 500 to 5,000 feet in breadth, and indented by drowned valley embayments more or less filled with deltas. On a number of islands the fringing reefs are so narrow and the bayhead deltas are so small that the submergence which lowered these islands to their present altitude must be of more recent date than that which lowered other islands, where the fringing reefs are already a mile or two wide and the deltas are well developed, and surely of much more recent date than the submergence which permitted the formation of the great fringing reefs, a mile or two broad, on Yap, in the Caroline group of the North Pacific, or on Rodriguez, a lonesome island in the Indian Ocean; more recent also than the submergence which determined the formation of the broad barrier reefs of Mbengha in Fiji, of Borabora in the Society Islands, and of the Great

Barrier of Australia. Hence not only does the absence of shore cliffs in the Philippines testify against the abrasion of platforms, on which so much weight is laid in the Glacial-control theory, but the submergences of different members of the Philippine group by different amounts and at different dates testify to local subsidences and not merely to a universal rise of ocean level.

THE SUBMERGED PLATFORMS OF THE PHILIPPINES

In view of the absence of shore cliffs, the submarine platforms which are to be expected in association with new fringing reefs, and which are well developed in certain parts, but not in all parts, of the Philippines, and which, furthermore, are sometimes imperfectly rimmed by reefs that do not reach the sea surface, may as above noted be much better explained as submerged and more or less aggraded reef plains than as abraded platforms cut on still-standing islands when the ocean was lowered in the Glacial period. The intermittent development and the varying depths of the platforms are strongly confirmatory of this view. For example, the long island of Palawan, which stretches 300 miles southwestward toward Borneo, is surrounded by an extensive submarine platform with a width of some 30 miles along the northwestern coast, where it is imperfectly rimmed by a discontinuous marginal reef that rises to depths of 10 or 20 fathoms. Opposite the middle of the island the platform sinks to depths of 50 or 60 fathoms, which is greater than can be accounted for by the Glacial-control theory; this part of the island coast is extraordinarily embayed, fringing reefs are almost wanting, and delta flats are small. If observation on the ground should discover signs of a moderate emergence along this part of the coast of later date than that of the submergence to which the embayments are due, then the submergence must have been for a time even greater than it is now. Farther south, in the neighborhood of Balabac Island, between Palawan and Borneo, the platform has a depth of only 25 or 30 fathoms, many isolated reef patches reach the sea surface, and the shore of Balabac has fringing reefs from two to three miles wide. Farther north a large part of the island of Luzon has a comparatively simple shoreline and no submerged platform; the lowland plains of this island seem to be the physiographic contemporaries of the submerged platform of Palawan.

These unlike features of the Philippines are much better explained by subsidence, varying in date, rate, place, and amount, than by any other process: northern Luzon seems to have stood almost stationary, while Palawan was downwarped. The frequent recurrence of depths of about 40 fathoms on the margin of many submerged platforms is, like the depth

of 40 fathoms at the change, already discussed, from a moderate slope to a steep pitch on the exterior profile of barrier and atoll reefs, much better explained as an aggradational adjustment of the platform margin to the present action of waves and currents than as recording a surface of abrasion that was cut when the ocean was 30 or 40 fathoms lower than now. The abundant and elaborately charted facts on which these statements concerning the Philippines are based merit detailed treatment, for which space can not be afforded here.

It may, however, be the case that those who are convinced of the correctness of the Glacial-control theory would insist that platforms and cliffs were really cut during the Glacial period on all the exposed coasts of the Philippines, and that they are not to be detected today because they have been greatly submerged or emerged since they were abraded; but if so great a measure of postglacial deformation is accepted for the Philippines, it is unreasonable to assume a long period of stability for the Macclesfield, Tizard, and other banks in the China Sea which the Philippines inclose from the Pacific; yet the processes of the Glacial-control theory involve a period of stability for the bottom of that sea long enough for the production of extensive banks by the degradation of volcanic islands, almost as large as Hawaii, to low relief chiefly by subaerial erosion in preglacial time, for their complete abrasion to submarine banks by the waves of the lowered ocean during the Glacial period, and for the more or less complete upgrowth of barrier reefs on the bank margins in postglacial time.

So long enduring a stability in a deep-sea basin bordering a continental margin of the Pacific Ocean seems to me not only inherently improbable on general principles, but seriously discredited by the many signs of geologically modern movements in the Philippines and elsewhere in the Australasian archipelagoes, whether such movements have caused the disappearance of abraded platforms and cliffs or not. The assumption of prolonged stability of the islands or banks thereabouts is, indeed, without sound support; no warrant for the assumption, based on an inquiry into the geological history of neighboring islands and continental coasts, has been published, and, as far as I can learn, no such warrant can be found. The explanation of the banks in the China Sea by the processes of the Glacial-control theory—among which two processes, the killing of the reefs and the abrasion of platforms, are already discredited by the absence of spur-end cliffs on the central islands of close-set barrier reefs in other regions—thus becomes improbable in a very high degree.

UNCONFORMABLE FRINGING REEFS IN SAMOA

According to the recent observations of Mayer, Tutuila, a well embayed member of the Samoan group, has strongly clift spurs, "some of the sea-cliffs being 500 feet high"; and the cliffs are fronted by a "fringing reef which forms a mere veneer over the modern offshore marine platform, and extends a short distance seaward, its precipitous outer edge being from 5 to about 20 fathoms deep" (1917, 523, 522). A recent small emergence is indicated, for "a platform about 8 feet above high tide juts out to seaward from the base of practically every promontory." The composition of this platform is not stated and its genetic relations are not explained, but it would seem to be a young platform cut at mid-height in partly submerged sea-cliffs. An unpublished chart of Tutuila, which I have lately had opportunity of seeing in the Hydrographic Office, Washington, contains a great number of new soundings, and reveals the existence of a submerged platform, from one to three miles in breadth and from 30 to 50 or more fathoms in depth, the presence of which could not have been proved by the scanty soundings of earlier charts. The outer part of the platform is usually somewhat shallower than at half distance offshore, as if a poorly developed barrier reef inclosed it; the most striking example of such a reef rises to less than 10 fathoms depth outside of Pagopago harbor, the chief embayment of the island; inside of this reef the platform has its maximum depth of 66 fathoms. Such a platform must have been backed with high cliffs, now partly submerged.

In view of these facts, it seems probable that the partly submerged cliffs of the spur ends were, like those of Tahiti, cut back by the sea when the island stood some 50 fathoms higher than now, and that the valleys, now embayed, were eroded while the cliffs were cut back, under conditions that prevented reef growth, as outlined on a later page. If this be the case, a rock platform of marine abrasion, from one to three miles in breadth, 50 fathoms or more below present sealevel, and covered by later deposits, must extend seaward from the submerged base line of the great cliffs; the imperfect barrier reef on the platform margin would then be explained as the first result of a moderate submergence, afterward followed by a rapid submergence, when the incipient reef was drowned and young cliffs were cut at mid-height in the great cliffs. The narrow platform of the young cliffs is now slightly emerged and margined by a fringing reef.

The Marquesas Islands resemble Tutuila, for the spur-ends of their embayed shorelines are strongly clift, and the cliffs plunge into water 10 or 20 fathoms in depth near shore, except that young cliffs and platforms are cut in the great cliff faces at present sealevel; but these islands

are still free from fringing reefs, as if their submergence were more recent than that of Tutuila. The above opinion about Tutuila is, however, only provisional, until fuller information is gained about the "modern offshore marine platform" beneath the fringing reef. It is therefore to be hoped that Mayer may be successful in his plan to bore through the reef and "study the existence or non-existence of a submerged marine platform" (1917, 526) underneath it.

The spur-end cliffs of Tutuila and the Marquesas Islands, as well as those of Tahiti, seem at first thought to give support to the Glacial-control theory of coral reefs; but in reality they contradict it, for if the cliffs of these exceptional islands were cut under the conditions which that theory postulates, then the central islands of all barrier reefs should be clift, and they are not. The cliffs of volcanic islands are best explained as the result of conditions determined by the islands themselves, as stated below.

UNCONFORMABLE FRINGING REEFS IN THE SOLOMON ISLANDS

Many other occurrences of unconformable fringing reefs of a new generation might be adduced, but space will be allowed only for a striking example on the small island of Fauro, in the western part of the Solomon group. The island is described by Guppy as "the basal wreck of some huge volcanic cone" (1887, 33); "so great has been the degradation of the surface that we have nothing more than the cores or basal remains of the ancient volcanic cones, which have built up this island" (40): some of the higher knobs consist of massive igneous rocks, and are interpreted as denuded volcanic necks (37). This painstaking observer says: "It is worthy of note that neither in this . . . island . . . nor in the adjacent smaller islands of volcanic formation did I find any raised coral rock. Narrow shore reefs fringe the coast" (38). Although Guppy mentions the "deeply indented sea-border" of Fauro as well as the great denudation that the island has suffered, he did not infer subsidence either from the embayed shoreline of the island, well shown in figure 11, or from the manifestly unconformable fringing reefs, or from the partly reef-rimmed platform that surrounds the island, on which the northward increase of depth strongly suggests a gentle tilting in that direction. On the contrary, he rejected Darwin's theory, which he had previously held, and regarded all the reefs of the Solomon group, whether at sealevel or above it, as having been formed during "an alternation of long periods of upheaval with lengthened intervals of repose" (127).

Not only so: Guppy's book was favorably reviewed in *Nature* and in the *Geological Magazine,* and the reviewers completely failed to notice the neglect of matters so manifest and so critically significant as embayed

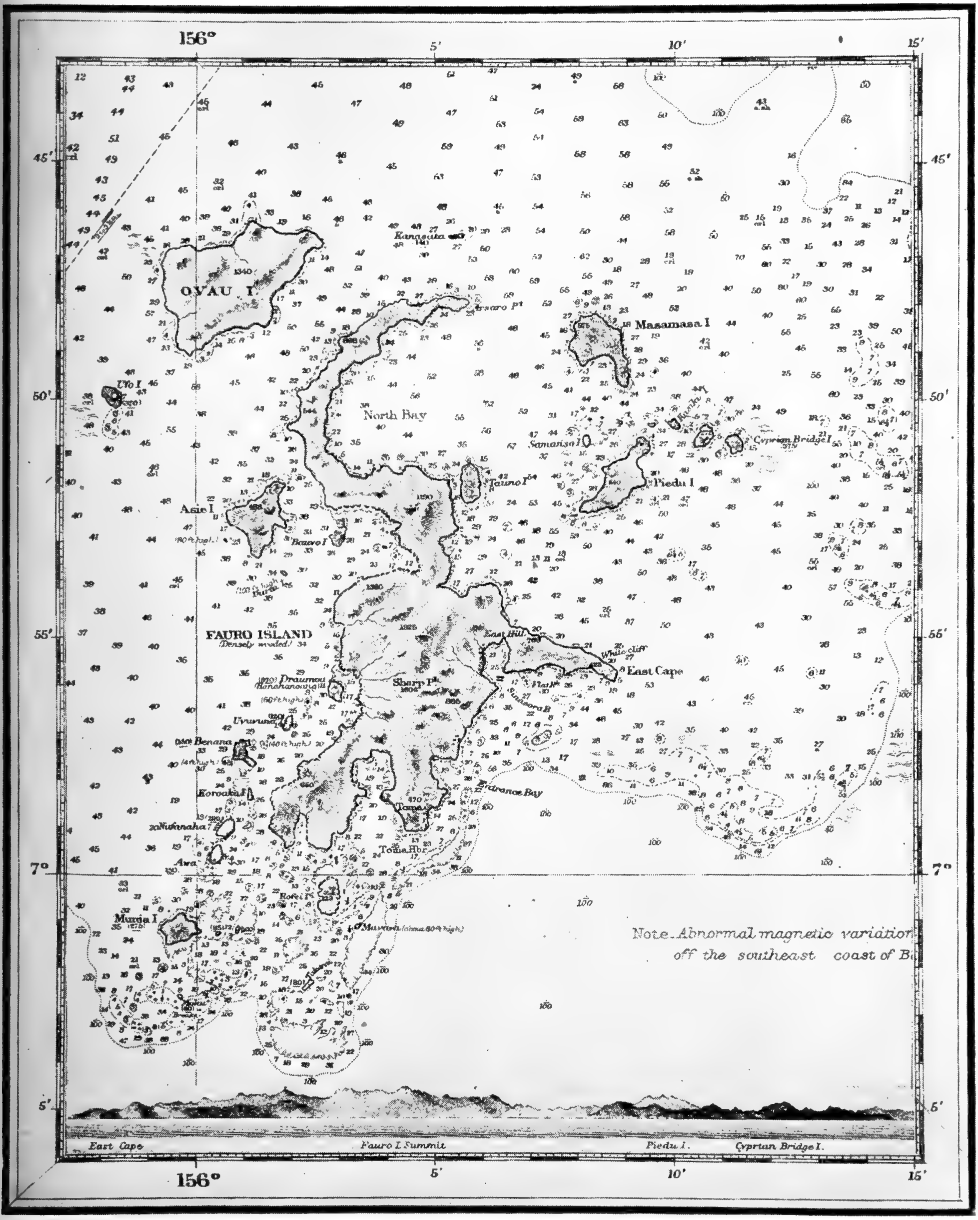

FIGURE 11.—*Fauro Island and its surrounding Bank, Solomon Islands*

From Hydrographic Office chart 2900

shorelines and unconformable contacts, the occurrence of both of which may be clearly inferred from the detailed accounts of the islands and reefs. One of the reviewers congratulated the author on having "demonstrated that the old theory [of subsidence] fails and the new [Murray's theory of outgrowth] succeeds"; the other commented on "the nervous reluctance of many geologists to accept any explanation of the origin of coral reefs unconnected with or adverse to the subsidence theory"; and urged that "no matter how great may be the authority of any one individual . . . if a series of facts, such as those recorded in the work before us, are plainly repugnant to the theory of subsidence, . . . it is the manifest duty of geologists especially to examine such facts without prejudice and to be ready to modify their views in accordance with the ever-advancing tide of scientific knowledge." The literature of the coral-reef problem is overcharged with uncritical and inconsequent discussions of this kind; for example, the Duke of Argyle's "Great Lesson" in the "Nineteenth Century" for 1887. It was in reply to this article that Huxley wrote an amusing comment in the same review, answering the charge that a "conspiracy of silence" was suppressing Murray's and Guppy's views in order to maintain the acceptance of Darwin's theory.

Distribution of Submarine Banks

REPLACEMENT OF ATOLLS BY SUBMARINE BANKS NEAR THE PHILIPPINES

The prevalence of unconformable fringing reefs on the embayed shores of the Philippines, in association with the irregular development and varying depths of submarine platforms, gives for Darwin's theory of intermittent subsidence a confirmation that is as strong as it is unexpected; and still further confirmation for this theory is found when the rarity of atolls in the region of the Philippines, already briefly alluded to, is further considered. For if the rapid subsidence, which has resulted in the submergence of previously formed fringing and barrier reefs and the establishment of many narrow fringing reefs of a new generation in that archipelago, extended to the adjacent seas from which no high islands emerge, it would there result in the submergence and more or less complete drowning of all preexistent atolls; and this is precisely what seems to have happened, for the number of submarine banks that appear to be drowned atolls in the region west of the Philippines is extraordinary. But atolls of good size, submerged or drowned by rapid subsidence, should be distinguished from small atolls that have been extinguished by decrease of diameter during slow subsidence, as seems to have been the case

with a number of minute reefs which I have described in Fiji and which are now brought to the surface again by elevation (1916, *b*).

The Sulu Sea, inclosed by the southern Philippines and Borneo, contains near its middle the Sultana bank, 18 miles long, with very little marginal reef; near by are the Kagayanes reefs, which imperfectly inclose a bank of similar length; farther south, where the occurrence of broader fringing reefs indicates a less rapid subsidence, the sea is occupied by smaller, atoll-like surface reefs of irregular development. The China Sea is much more remarkable for the number of its submarine banks, of which the Macclesfield, above mentioned as lying in the center of this sea, is the largest. Westward from the Macclesfield bank, a third or half way to the coast of Tonquin China, a number of smaller banks are partly rimmed with reefs, as if subsidence were of smaller measure or slower in that direction. Farther south is a remarkable group of banks—the Tizard, Rifleman, Prince of Wales, Prince Consort, and Vanguard—with imperfect reef rims or with no rims, and with varying depths, as will be more fully shown below.

It may here be noted that Niermeyer (1911) and Wichman (1912) have called attention to the relative rarity of atolls in the East Indies and to the small size of those that occur. Both these authors, although differing in other points, agree that the reefs which are found there can not be explained according to Darwin's theory: but the discussions are so incomplete—the evidence of embayments and unconformities being overlooked—that the conclusion seems untrustworthy. Sluiter's explanation of the scarcity of reefs in the shallow Java Sea, 10 or 20 fathoms in depth, as a consequence of the inability of corals to establish themselves on the muddy bottom (1889), is better supported. Whether atolls were more numerous in the southern archipelagoes when the non-embayed islands stood lower will be determined by future exploration; Roti, near Timor, must, according to Brouwer (1914), have been an atoll when its highest limestones were formed, and certain other limestone islands, less satisfactorily described, appear to be of the same origin.

It seems impossible to make the peculiarly grouped facts of the Philippines and the China Sea accord with the sharply defined requirements of the Glacial-control theory, though they accord remarkably well with the more elastic requirements of the theory of subsidence. One theory demands that atoll lagoons and submarine banks shall have depths of about 40 fathoms or less; that islands shall, as a rule, be bordered by platforms of similar depth, fronted with barrier reefs and backed with partly submerged cliffs; that the cliffs shall not be interrupted by embayments of

greater width or greater rock-bottom depth than can have been eroded while the ocean was lowered in the Glacial period; and that the geological history of the islands shall, as a rule, indicate recent stability and shall not discountenance too strongly a long period of stability for neighboring atolls and banks.

The other theory does not set any small or uniform limit to the depth of lagoons and banks or to the depth of platforms along island borders; it demands that such platforms shall be, as a rule, backed by an embayed and not clift coast, but the embayments may be of any dimensions, and the geological history of the islands may indicate any degree of stability or disturbance. The chief features of this theory are that when a coast stands still reefs shall grow outward from it; that when subsidence does not take place too rapidly it shall be accompanied by a corresponding reef upgrowth; and finally that when subsidence takes place more rapidly it shall for a time at least cause the submergence of preexistent reefs. Rapid subsidence should therefore produce drowned atolls or submarine banks in the open sea, while along island coasts it would change surface reefs into submerged platforms fronted with incomplete barriers and backed with fringing reefs of a new generation on an embayed and little clift shoreline. The submarine banks of the China Sea and the fringing reefs and submerged platforms of the Philippines give unexpectedly strong corroborating testimony for the second theory.

SUBMARINE BANKS IN THE PACIFIC AND INDIAN OCEANS

Fifteen or more submarine banks of moderate or small size occur north of the Fiji group, as will be more fully stated below. Several larger banks occur around the Tonga Islands; their variations in depth strongly suggest slanting subsidence. Apart from these examples, few others are known in the vast area of the central Pacific. On the other hand, the central Indian Ocean, much less provided with atolls than the central Pacific, contains a good number of extensive submarine banks, brief account of which will be given in a later section on the unequal depths of banks and lagoons. Submarine banks are therefore not distributed equally through the coral seas; they occur in groups, as if controlled by some local process. When all factors of the problem are considered, the most probable process of the kind is accelerated regional subsidence. Submarine banks may therefore be regarded with good reason as drowned atolls.

The group of banks north of the Fiji Islands gives, to my reading, remarkable support to this view. It occupies a region measuring about 200 miles north-south by 800 miles east-west, between the Samoa Islands

with their active volcanoes on the east, the Ellice group of atolls on the north, the Santa Cruz, Banks, and New Hebrides Islands with active volcanoes on the west, and the Fiji archipelago on the south. Its members vary from less than a mile to over 20 miles in diameter, and from 10 to 30 fathoms in central depth. It is difficult, if at all possible, to explain these banks under the uniform conditions of the Glacial-control theory; for if preglacial atolls and barrier reefs were cut down during the Glacial period and have now been built up to the surface again in the Ellice group on the north and in the Fiji group on the south, they should have been similarly built up in the intermediate area; yet there they remain below sealevel. It is, on the other hand, a simple matter to explain this extraordinary group of banks under the variable conditions of Darwin's theory merely by postulating moderate inequalities in the rate or amount of recent subsidence, the greater or more rapid subsidence being in the region of the submarine banks, and the smaller or slower subsidence being to the north in the Ellice group and to the south in the Fiji group.

But it is evidently desirable to find some independent confirmation for the postulate of recent and rapid subsidence in the region of these banks, such as neighboring high islands might furnish, similar to the confirmation given by the submerged bank bordering the embayed and fringed shore of Palawan for the recent and rapid subsidence of the banks in the China Sea; for it is plain that if high islands occurred in or near the region here under consideration, they should have been surrounded by sealevel barrier reefs when the now submerged banks existed as sealevel atolls, but that their barrier reefs should now be more or less submerged as a result of the rapid subsidence by which the atolls were converted into submarine banks; and inasmuch as submerged barrier reefs are rarely found, the occurrence of one in this particular region would be significant.

By good fortune, two high islands occur in association with this group of submarine banks. Uea or Wallis island is in the southeastern part of the area; it is shown on Hydrographic Office chart 2019 to be 6 miles long, about 200 feet high, and surrounded by a barrier reef about 2 miles offshore: subsidence here must have been at a moderate rate. More important is Rotuma, near the center of the area; chart 1978 shows it to be 7 miles long, 690 feet high, and closely surrounded by a fringing reef; but it rises eccentrically from a submarine bank, 3 miles wide on the north and extending 6 miles to the west; the bank is for the most part 25 or 30 fathoms deep, but it has a rim about 15 fathoms deep; hence it is an excellent counterpart of a submerged barrier reef, such as the subsidence theory suggests should occur here. Whale bank, a rimless shoal,

3 miles long and 15 or 20 fathoms deep, lies a mile farther on the west.

Gardiner is the only student of coral reefs who has described Rotuma in detail. His accounts permit one to suppose that the eccentric position of the volcanic island with respect to the bank is due to the recent unsymmetrical addition of new cones to an older island that was more centrally situated. It may indeed be by reason of the "broad lava streams" which "can be traced to the sea" from several craters, the appearance of which led to the belief that "they have not been long inactive" (1898, *a,* 438), that "the coast is fairly even with a complete absence of the 'long points and deep fiord-like bays' which, according to Dana, would on a volcanic island give indubitable evidence of subsidence" (499). Some of the recent ash cones are clift to a height of 700 or 900 feet, this being a natural result of the absence of reefs around their young shoreline; but they now have narrow fringing reefs; one of these, a few yards wide, drops off abruptly into 20 fathoms of water (440). As to the fringing reefs, it may be agreed that they have "been formed entirely at the present level" by outgrowth; but the submarine bank and its 15-fathom rim, together with the plunging cliffs, strongly suggest that rapid submergence has taken place here as well as in the area of the isolated banks.

Inasmuch as, with the exception of Tutuila, described above, there is no other known example of a submerged barrier reef so good as Rotuma in the vast extent of the open Pacific, its occurrence in close association with the chief group of Pacific submarine banks has an almost demonstrative value for the subsidence theory; for, as Darwin said, "If an old barrier reef were destroyed and submerged, and new reefs became attached to the land, these would necessarily at first belong to the fringing class." It is interesting to note that the young naturalist went on to say that, fringing reefs being all colored red on his maps as indicating stationary or rising coasts, examples of exceptional fringing reefs, formed as above suggested, would be given the same color, "although the coast was sinking"; but he added, "I have no reason to believe that from this source of error any coast has been wrongly colored with respect to movement indicated" (124). With reference to Rotuma, it is later said in explanation of the colors on the chart of reef distribution: "From the chart in Duperrey's atlas, I thought this island was encircled [that is, by a barrier reef], and had colored it blue; but the Chev. Dillon assures me that the reef is only a shore or fringing one, red" (162). One may imagine the pleasure that Darwin would have felt on learning more fully the facts about this curious island and the numerous "drowned atolls" with which it is associated, and thus recognizing that he might restore the blue color originally assigned to Rotuma. One may, indeed, here quote what Geikie

has so well said of Darwin, though with a somewhat altered application: "No one would have welcomed fresh discoveries more heartily than he, even should they lead to the setting aside of his own work."

Various additional details regarding certain islands of neighboring groups might be given in confirmation of the postulate of rapid subsidence for the region of these submarine banks, but space can not be granted them here. I propose, however, that this group of banks should be called the "Darwin hermatopelago," hermato being from the Greek word for "submerged reefs."

THE SEYCHELLES BANK

It is evidently conceivable that the various submarine banks mentioned in earlier paragraphs are neither drowned atolls, as they are supposed to be under the theory of subsidence, nor stationary islands truncated by abrasion, as they are supposed to be under the theory of Glacial-control; but still-standing submarine mountains that have been built up to a moderate depth by pelagic aggradation, as is supposed under Murray's theory of atolls. The improbability of so stable an origin for the banks of the China Sea and of the Pacific north of Fiji is very great. Most of the great banks of the Indian Ocean stand so far from high islands of a decipherable history that their origin is more in doubt; the Seychelles bank, however, is surmounted by several high islands, and if this bank may be taken as a fair sample of its neighbors, their stability is improbable, to say the least.

The vast bank of the Seychelles in the Southern Indian Ocean, the largest bank in the coral seas, measures about 200 by 80 miles and has a maximum depth of 40 fathoms near its center; its northeastern side is partly reef-rimmed, and a few small coral islands there reach the surface. Near the center of the bank several mountainous granitic islands emerge; the largest of them, Mahé, rises to an altitude of 2,993 feet; its shoreline has many bays divided by sloping, non-clift points, around which unconformable fringing reefs are formed; such features testify immediately for instability of their region. The present depth of the great bank is not excessive, but there is an elevated fringing reef on Mahé at a height of 80 feet; and when that was at sealevel the central depth of the bank must have been over 50 fathoms. Thus uplift as well as subsidence has occurred here. The abrasion of a bank so large as that of the Seychelles during the Glacial period is in any case altogether improbable, and all the more so as the granitic islands near its center are not clift. However, if abrasion be assumed, the present depth of 40 fathoms might possibly be explained as a result of wave-work by the

lowered Glacial ocean; but the former depth of 50 or more fathoms, at the time when the elevated fringing reef was forming, can not be safely explained without subsidence.

On the other hand, even with the aid of subsidence, it may seem difficult to explain the vast Seychelles bank as a drowned and partly rebuilt almost-atoll, for its dimensions are far greater than those of any known sealevel atoll. The difficulty here is, however, more apparent than real, for while the time demanded for the production of a bank by edgewise abrasion increases more rapidly than the increase of its diameter, the aggradation of an atoll lagoon by locally formed sediments, such as are provided by floating foraminifera and bottom nullipores, is independent of the diameter, inasmuch as the agency here grows with the area. Hence if this bank be a drowned almost-atoll, it may have as small a proportion of coral-reef limestone to lagoon limestone as Vaughan has found in the reef and lagoon area of southern Florida. The upshot of all this is that in so far as the Seychelles bank may speak for its neighbors, the submarine banks of the Indian Ocean have suffered changes of level in late geological time; and this is more consistent with Darwin's theory of coral reefs than with any other.

RECENT ORIGIN OF GREAT OCEAN DEPTHS

In view of these various considerations one is led to think that, as Suess has suggested, the deep mediterranean seas, of which the China Sea is a typical example, resemble lofty mountains in resulting from comparatively recent deformation. Certain members of the Philippines as well as the bottom of the neighboring China Sea basin may therefore be regarded as having, on the whole, subsided so much, so rapidly, and so recently that reef upgrowth could not keep pace with their submergence. They are therefore characterized rather by imperfectly rimmed submarine banks and by narrow fringing reefs of a new generation than by barrier reefs and atolls. I believe the same statement may be made regarding various other parts of the Australasian archipelago, not that subsidence alone has taken place in this great region, for elevated reefs occur on various islands up to altitudes of 1,000 or 2,000 feet; but that diverse and rapid downward movements of the sea borders and basins, often associated with corresponding upward movements in the larger islands, to which Molengraaff (1916) and Abendanon (1917) have lately given much emphasis, result in the present prevalence of fringing reefs here, in association with submerged barrier reefs and atolls, while sea-level atolls and barrier reefs prevail in the quieter regions of the open Pacific, where submerged atolls are almost unknown. It is certainly

remarkable that the best explanation for the fringing reefs so prevalent around the shores of the Philippines is to be found in the brief passage above quoted from young Darwin's book, in which their origin was clearly stated though the unconformable nature of their contact with the shore rocks was not mentioned.

In this connection it is desirable to point out that certain ocean-bottom troughs of exceptionally great depth occur in close association with islands of more or less disturbed history, from which the recent deepening of the troughs may be inferred. Thus a long deep trough closely adjoins the Philippines on the east. Another passes next to the east of the Pelew Islands, where recent tilting is indicated. A third lies next west of the Solomon Islands, and a fourth lies west of the New Hebrides, in both of which groups many and diverse modern changes of level are inferred. A fifth lies east of the Tonga Islands and banks, where recent tilting has occurred. Whatever degree of quietude may be inferred for other parts of the Pacific, these areas can hardly be regarded as having long enjoyed a stationary condition.

Disappearance of Detritus from deeply eroded Islands

CONDITIONS OF REEF ESTABLISHMENT

Reef-building corals need a firm rock foundation for their attachment and clear water free from wave-shifted detritus for their growth. Reefs are therefore wanting on beached shores, from which a sheet of detritus, supplied by streams and waves, usually extends offshore into deep water. Incipient reefs formed on a rocky shore will be destroyed if detritus is spread over them by wave or current action. In the absence of reefs on shores thus characterized, a cliff-backed platform will be abraded along them; and as long as no change of level takes place, the sheet of detritus, which ordinarily lies on such a platform and which is shifted about at time of storms, will be maintained and reef growth will be excluded. Only when subsidence takes place rapidly enough to drown the valleys and pocket their stream-washed waste in embayments, and to submerge the cliff base so that waves beat ineffectively on the cliff face, may reef growth begin, either as a fringe on the cliff face or as an offshore reef which may grow up as a barrier from ledges laid bare on the margin of the submerged platform, where detritus, no longer supplied, has been drifted away.

CLIFT ISLANDS IN THE CORAL SEAS

If these principles are correct, it follows that no large reefs can be formed around the shore of a lofty young volcanic island; for even if

fringing-reef patches are formed here and there on lava points, detritus will be so abundantly supplied by actively outflowing streams that the incipient reefs will be smothered. Wave action will thereupon set in, and the island will be benched and clift as long as no change of level occurs. It is thus that the scarcity of reefs is explained around the immaturely dissected volcanic island of Reunion, where the retrograded cliffs have well developed beaches along their base and where the non-embayed valleys are fronted by still wider beaches. The former absence of reefs and the cutting of high cliffs around the immaturely dissected island of Tahiti must be similarly explained; the fringing and barrier reefs that now imperfectly encircle that island must have been formed after submergence, presumably due to subsidence, had drowned the cliff-base and embayed the valleys to a depth of 600 or 800 feet, as I have briefly stated elsewhere (1916, *a*), and as is much more fully set forth in the forthcoming article in the *Annales de Géographie,* above mentioned. The cliffs and reefs of Tutuila may be provisionally explained in the same way, as noted above.

REEFS AROUND DEEPLY ERODED ISLANDS

Many other volcanic islands, much more deeply and maturely dissected than Reunion and Tahiti, are surrounded by barrier reefs; and it has usually been assumed that such reefs began their growth when volcanic action ceased, and continued their growth, according to Darwin's theory, as the island subsided. Other theories, however, assume that reef-encircled islands have not subsided, and that their barrier reefs have been formed by the outgrowth of fringing reefs. If the physiographic development of the deeply dissected islands be attentively considered, both of these explanations for their reefs become untenable. Not only are the embayed shorelines and the unconformable reef contacts of such islands beyond explanation by all theories which assume still-standing islands, but in view of the enormous volume of detritus that has been discharged from the islands in the course of their deep dissection, the reefs are also beyond explanation as continuous upgrowths on slowly subsiding foundations since eruptions ceased.

In the maturely dissected island of Huaheine, in the Society group, the volume of detritus discharged during the erosion of the former volcanic cone is from 50 to 70 times the volume of the lagoon inclosed by the present barrier reef; in the skeleton island of Borabora of the same group the ratio of discharged detritus to lagoon volume is probably greater still. In Murea, near Tahiti, in the Society group, the enormous volume of discharged detritus may be inferred from the depth and width of its valleys, as sketched in the upper part of figure 12; the narrow lagoon,

half a mile across, is so foreshortened as not to be visible between the barrier reef and the shore, both of which are shown by the same sea-level line. In Rarotonga, a lofty member of the Cook group, drawn in the lower part of figure 12, the shore lowland consists of a slightly elevated reef, which would have been completely smothered by detritus if the deep valleys had not been eroded and the island partly submerged before the reef began to grow. The transformation of Fauro, figure 11, in the Solomon group, from the initial form of a volcanic cone or group of cones into the present "wreck" of branching ridges surmounting a submerged platform, 40 fathoms or more in depth, is utterly impossible by any combination of erosion and abrasion, without the aid of recent subsidence.

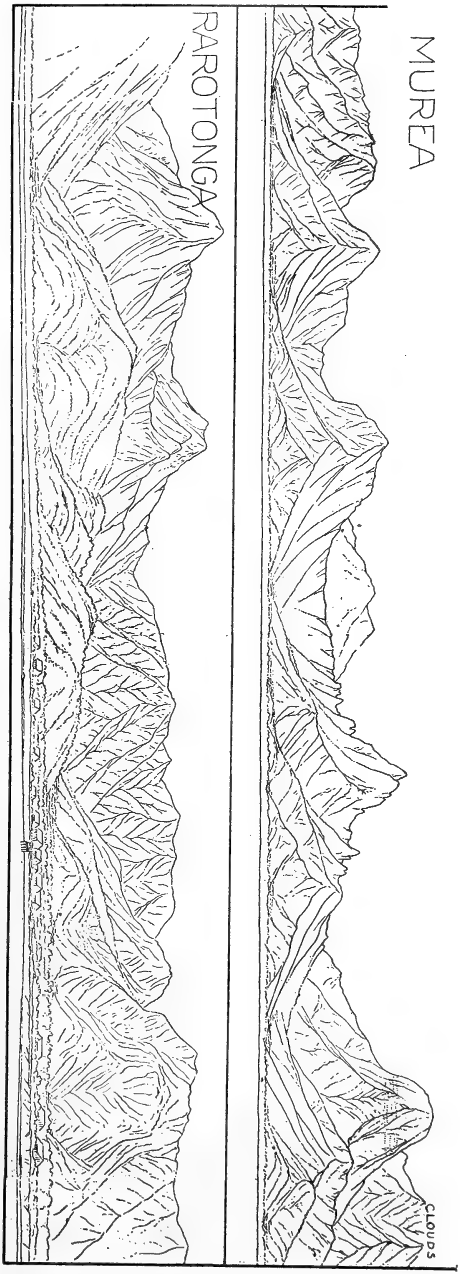

FIGURE 12.—*Murea Island, of the Society Group, and Rarotonga, of the Cook Group*

Any incipient reefs that may have been formed around the shores of these islands before the erosion of their valleys must have been soon overwhelmed by outwash detritus; cliff-cutting must have thereupon set in, and thereafter the excess of detritus delivered

from the valleys and detached from the cliffs must have been swept offshore by the cliff-cutting waves. If no subsidence had taken place, the islands would be today not reef-encircled but cliff-rimmed. Even if the changes of ocean level during the Glacial period be considered, high cliffs must have been cut around the still-standing islands in preglacial time; and the erosional and abrasional changes accomplished during the Glacial epochs of lower sealevel could not have transformed the cliff-rimmed and non-embayed islands of preglacial time into the non-clift and broadly embayed islands of today.

The only reasonable explanation that I have been able to invent for the disappearance of the great volume of detritus shed from a deeply dissected, reef-encircled island involves the aid of wave abrasion during a considerable reef-free period of erosion before subsidence began or when it proceeded slowly, and the absence of effective abrasion during a following period of greater or more rapid subsidence of the island accompanied by reef growth, after erosion was well advanced. Under such conditions, most of the detritus would be swept offshore and deposited, while subsidence was slow or absent, on the submarine flanks of the island before it was encircled by reefs; after subsidence became rapid or great enough to permit reef establishment and upgrowth, the coarser part of the detritus still to be discharged would be laid down in embayment deltas, and some of the finer part would be swept out of the lagoon through the passes in the reef, which were probably broader and more numerous in the earlier stages of reef growth than they are today.

THE SUBMERGED CLIFFS OF REEF-ENCIRCLED ISLANDS

If the processes thus sketched have really taken place on such islands as Huaheine and Borabora, they must have once had a rock platform, DE, figure 4, and strongly clift spur ends, EF, around their shores; if the platform gained a width of a mile, the spur-end cliffs must have had a height of 1,000 or 1,300 feet. But Huaheine and Borabora have tapering spurs, at the ends of which any little cliffs that occur, as at B, have been cut by lagoon-wave abrasion at present sealevel, for they rise at the back of narrow, low-tide rock platforms. Hence the greater cliffs, that were presumably cut before reef growth began, have disappeared by submergence, and submergence of so great an amount as is here implied can be accounted for only by subsidence.

It is not necessary, however, that the island should have stood still and that the inferred platform and cliffs should have been cut back to a great breadth, DE, and height, EF, before any subsidence took place; it suf-

fices, as above noted, that subsidence should proceed so slowly as not to interrupt cliff-cutting, but rather to aid it by gradually and continually deepening the water on the abraded platform, and thus allowing the attacking waves to reach the cliff face with much less diminished force than if no subsidence took place. Thus the platform might be more inclined and the cliff lower than if they had been cut during a long still-stand, or the platform and cliff might be subdivided in many little treads and rises. But in order to explain the growth of a wide-lagoon barrier reef, R, offshore from a steep-sloping island, AB, after a series of small treads and rises had been cut during intermittent subsidence instead of a broad platform during a stationary period, abrasion must have begun farther down the volcanic slope, as at C, and ceased at D, so that reef growth beginning at D could rise to R; and this involves a greater total subsidence than the preceding supposition requires.

It is possible that occasional more rapid subsidences during the abrasion of the benched slope, CD, permitted the temporary establishment of reefs, Q, which grew upward until they were overwhelmed by outwashed detritus, whereupon abrasion would again set in. But eventually, when the discharge of detritus was decreased by reason of the advanced stage of island erosion then reached, subsidence, especially accelerated subsidence, would gain the upper hand; the reefs thereupon established would thereafter persist, and thus the present condition of a reef-encircled, embayed, non-clift island would be attained.

This evidence for Darwin's theory is manifestly of a theoretical nature; but the evidence supplied by unconformable reef contacts is also theoretical. The difference between the two lines of evidence is not so much that one is theoretical and the other is not, as that the principles and processes involved in one are here applied in a novel manner and are not yet generally accepted, while those involved in the other have long been familiar in geological science and are universally accepted, even though they have not been usually utilized in the coral-reef problem.

Absence of Reefs on Coasts of Emergence

REEFLESS COASTS IN THE AUSTRALASIAN ARCHIPELAGOES

Conditions favorable to reef establishment are not, as a rule, provided on coasts of recent emergence, because the simple shoreline and the smooth adjacent sea-bottom are occupied for scores of miles together by unconsolidated sediments on which corals can not grow. In the absence of reefs such coasts are attacked by the waves and cut back, except that where large rivers mouth their deltas may be built forward. Stationary

coasts of more ancient emergence are also generally ill adapted to reef establishment, because as long as they stand still the frontal slopes of the deltas that are built forward and the broad surface of the platforms that are cut backward are overspread with shifting detritus, on which corals can not attach themselves. Moreover, in virtue of coastal emergence, the rivers of the region will, as a rule, be revived to more active erosion than before; the detritus that they discharge, added to that spread from the cliffs by the waves, will cloak the platform with loose sediments and prevent coral growth. The following examples may be cited:

Part of the southwest coast of Sumatra is, according to Erb (1905), a coastal plain of Pliocene strata, bordered by a beach of gravel beaten by heavy surf and drifted northwestward by the long-shore current; discontinuous fringing reefs are found near the southeastern end of the coast, where the gravel beach is less developed, and some of them are attached to the eroded margin of uplifted reefs which stand 20 or 30 meters above sealevel and seem to offer a firm support for the new growths. The southwest coast of Java as described by Guppy consists of a coastal plain of gently inclined foraminiferous tuffs, and seems to offer an example of a simple shoreline of emergence in a later stage of development than that of Java, for it has been retrograded so that the emerged strata are cut off in a bluff, 40 or 50 feet in height (1889, *a*). Beneath the bluff lies a beach of dark volcanic sand, on which the heavy surf breaks unrestrained by coral reefs. But fringing reefs do occur on short stretches of the shore, and "there was a time, in fact, when a large portion of this coast was fronted by shore reefs, which have since been killed and overwhelmed by the great quantities of sand and mud brought down by the rivers (1889, *b*, 630). The last statement seems to justify one of the principles adopted above in the section on the development of clift volcanic islands in the coral seas.

Borneo appears to be, according to Molengraaff, reef-free around most of its shoreline, because of the abundant outwash of detritus since its late Tertiary uplift, whereby extensive alluvial deltas have been built forward from the margin of its emerged coastal plain; it is "a worn, much denuded mountain land, surrounded for the greater part by broad tracts of low land, covered with fluviatile deposits . . . the result of prolonged and intense erosion of a mountainous island surrounded by a shallow sea" (1902, 453). Coral reefs seem to have been absent previous to the late Tertiary uplift as well as now, for the mass that then emerged is described as an older nucleus unconformably surrounded by nearly horizontal coal-bearing strata, which were presumably formed under conditions very similar to those obtaining on the aggraded fluviatile lowland of today.

The Gulf of Carpentaria, on the northern coast of Australia, is shown on the geological map of Queensland by Jack and Etheridge (1892, map, sheet 5) to be mostly bordered by low alluvial delta flats, often occupied by mangrove swamps. The shallow sea-border is free from reefs, and thus presents a strong contrast to the eastern coast of Queensland, where reefs abound along a bold embayed coast fronting deep water. Whether this example belongs under coasts initiated by emergence or by submergence I can not say. Young volcanic islands may be treated under coasts of emergence; their shorelines are comparatively simple, and the detritus washed from their slopes may form a gravelly or sandy beach. Ambrym, in the New Hebrides, culminating in an active volcano from which streams of lava and showers of dust have been given forth in recent years, has a beach and bluff cut in loose ash deposits along part of its circuit; here reefs are absent and the surf becomes dark and turbid as it falls on the black volcanic sand.

THE REEFLESS COAST OF SOUTHEASTERN INDIA

The Madras district of southeastern India, of which Cushing (1911, 1913) has given excellent descriptions, is a remarkable example of a

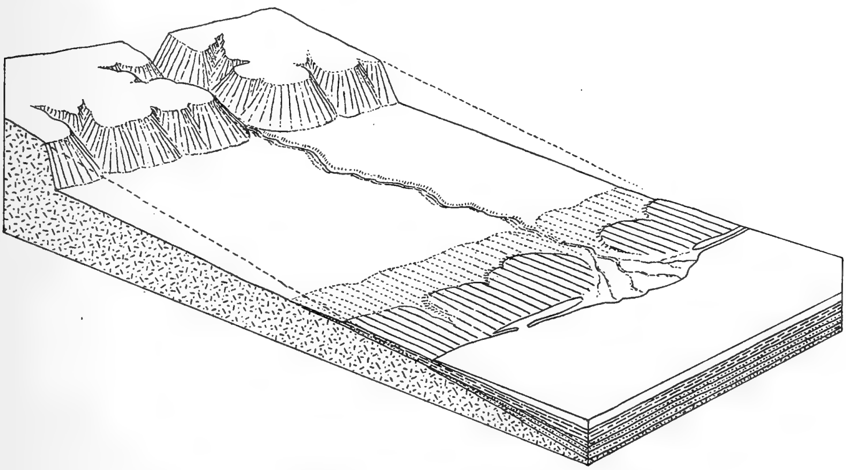

FIGURE 13.—*Diagram of the reefless Coast of Madras*

reefless coast of subrecent emergence. It is bordered by a belt of marine strata, forming a coastal plain the shoreline of which is either fronted by sand reefs or built forward by deltas, roughly shown in figure 13; but coral reefs are almost wanting in spite of the high temperature of the sea-water. Furthermore, a much more ancient emergence of this region, by

which the interior highlands gained most of their altitude, must also have had a reef-free shoreline, as in block B, figure 14, for previous to the sub-recent emergence of the coast the seaward slope of the uplifted highlands had been cut back many miles by the waves, thus producing a broad and low rock-platform backed by high cliffs, block C, which are now, since the later emergence, seen inland from the low coastal plain, as in block D, figure 14, or as in figure 13.

This region may therefore be taken as exemplifying the principles above stated regarding coasts of ancient as well as of modern emergence, and as warranting another of the principles expressed above in the section

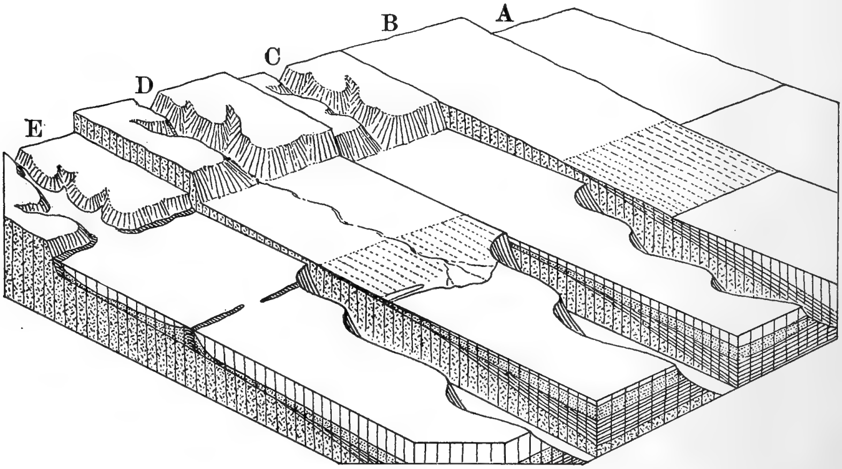

FIGURE 14.—*Evolution of the reefless Coast of Madras*

on clift islands in the coral seas, to the effect that as long as a coast of emergence stands still enough not to interrupt the action of abrasion in wearing it back, no reefs can be formed along its shore. If, then, reefs can not be developed on coasts of emergence, either at the time of emergence or during a succeeding stationary period, they must be developed on coasts of submergence.

REEFS ON COASTS OF SUBMERGENCE

The bearing of the reef-free condition of coasts of emergence on the coral-reef problem will be clearer if the favorable conditions for reef growth on coasts of submergence are considered. Unlike the simple shoreline of a coast of emergence, the shoreline of a coast of submergence is of irregularly varied pattern: it usually presents a succession of ad-

vancing headlands and outlying islands alternating with reentrant embayments branching into many coves. The headlands are soon swept clear of detritus, and thereupon they become bordered by outgrowing fringing reefs and are thus protected from further wave attack. The bayheads on the contrary are invaded by delta deposits and, if submergence cease, any fringing reefs at first formed in the bays are in time overwhelmed. The longer such a coast stands still, and the higher and larger and rainier the drainage area of its rivers, the farther forward will the deltas advance; the detritus may indeed be eventually drifted so abundantly along the prograding shore as to smother the headland reefs: thereupon the waves will cut away the dead coral rock, and the delta fronts also if the rivers are not too strong, and in time the waves will attack the headlands again. It thus seems eminently possible that the coast of a considerable land area that was bordered with reefs for a time after submergence took place, will later become reef-free and so remain as long as the land stands still and the shoreline suffers uninterrupted abrasive retrogression.

It is manifest, however, that this untoward result may be prevented if the submergence of the coast be intermittently continued at frequent intervals; for if the bays are lengthened and deepened and the headlands are shortened by renewed submergence before detritus overwhelms the previously established reefs, the reefs will grow upward and more or less outward, and will thus be transformed into discontinuous barrier reefs; at the same time new fringing reefs will grow on the shortened headlands, and the intermediate lagoon will be aggraded with deposits inwashed from the outer reef and outwashed from the land, as well as by organic deposits formed in the lagoon itself. It also appears probable that small islands, once partly submerged, will retain their reefs indefinitely in a succeeding stationary period, because the detritus that they shed will not suffice to fill the lagoon and smother the corals on the reef face. This scheme represents, I believe, the ordinary condition of reef growth, for most reefs occur on mountainous coasts of long-continued submergence, as has been shown in the preceding chapter; in other words, reefs are ordinarily formed as Darwin explained. In case renewed submergence should be more rapid than reef upgrowth, the previously formed reefs will be drowned and fringing reefs of a new generation will be formed along the new shoreline; and reefs of this kind are also, as has already been shown, explained by a special phase of the theory of subsidence which Darwin explicitly announced.

If our observational acquaintance with the coasts of the world covered several geological periods, we might reasonably expect to find actual examples of reef-fronted and reef-free coasts in all stages of development

here sketched; but our acquaintance is limited to a geological moment known as "the present," and our knowledge of even the present condition of many coasts is not yet intimate, for it has not been gained by a scrutinizing inquiry during which all problems of coastal development were consciously held in mind. It is therefore natural enough that some of the stages of coastal development above outlined should not yet have found their counterparts in nature. The best that we can now do is to discover counterparts for as many stages as possible; we may then, according to the success with which some of the deduced stages match the facts, judge of the correctness of the other stages and thus of the whole sequence of changes involved in our theoretical scheme. Coasts of recent or of long-continued submergence will first be considered; coasts of less recent submergence will next be examined.

REEFS ON COASTS OF RECENT AND CONTINUED SUBMERGENCE

Reefs are, as above stated, abundantly developed on coasts of submergence in which the embayments are not yet filled with deltas. The lowering of the Glacial ocean may have contributed to this result by enabling the streams to wash away the detritus which had previously accumulated, but, as has been shown in several previous paragraphs, the changes of ocean level thus accounted for do not suffice to explain nearly all the erosion and submergence that many reef-fronted coasts have experienced. Long-continued, intermittent subsidence, varying in place, amount, time, and rate, and not infrequently alternating with elevation, is demanded by the multitude of varied facts. This point need not be dwelt on longer.

SMOTHERED REEFS ON COASTS OF LESS RECENT SUBMERGENCE

The mountainous and embayed coast of southern New Guinea is fronted by barrier reefs for much of its length, but in a large reentrant near its middle the Fly River—named after the British exploring vessel on which Jukes was geologist—has formed an extensive delta prolonged in muddy shoals; here reefs are now absent, but it is highly probable that they were present along parts of this coastal reentrant before the delta gained its present size. The great deltas of the Irrawaddy in Burma and of the Mekong in Cochin China are built forward from coasts of fairly strong relief, that have been embayed and morcellated by submergence; reefs are wanting on the delta deposits, but they occur in patches on the adjoining coasts. Many smaller examples of this kind are known in the lagoon of the Great Barrier reef of Australia, where advancing deltas have apparently smothered previously formed fringing reefs. Certain stretches of

the coast of Tahiti, where the last important movement was a submergence, are now fronted by reef-free beaches of volcanic sand, where the deltas of the larger streams have outgrown the embayments in which their formation began. Reasons might be adduced, if space permitted, for inferring, in advance of observation, that smothered reefs exist under the coastal lowlands of Luzon.

No examples have been found to illustrate the general retrogradation of a delta-fronted coast of submergence, but a complete search of existing coasts has not yet been made with this object in view. It may well be, however, that the postglacial rise of ocean level has, in combination with movements of subsidence, held the development of most coasts back to an earlier stage than that in which general retrogradation should be expected. There are reasons which I have elsewhere set forth for thinking that the Great Barrier reef of Australia, which today incloses a broad lagoon, had reached a more advanced stage of development before the last strong subsidence of its region, and that its lagoon may then have been converted into a plain, across which the rivers from the rainy highlands of the back country carried their detritus to the reef front and overwhelmed its corals (1917, *c,* 350).

REEFS ON COASTS OF EMERGENCE, AFTERWARD SUBMERGED

It is evident from the foregoing discussion that a reefless coast of emergence may be converted by submergence into a reef-fronted coast. I have not yet found any examples in which a reef-free coastal plain of emergence has after partial dissection suffered so recent a submergence as to be bordered only by newly established fringing reefs; but the southern coast of Viti Levu, the largest island of the Fiji group, is an example of a somewhat later stage of this sequence, as it is bordered by a dissected and embayed coastal plain, reference to which was briefly made in an earlier paragraph, and fronted by a barrier reef that is on the verge of being overwhelmed where the deltas of two large rivers are advancing toward it. The island is chiefly composed of resistant volcanic rocks, on which the coastal-plain series of marine strata, formed of foraminiferous volcanic muds and locally known as "soapstone," has been unconformably laid down. Since their emergence along the southern coast the strata have been maturely dissected, so that they no longer form a coastal plain but a littoral belt of hills; and since their dissection they have been partly submerged, whereby their shoreline became well embayed.

The strong offshore barrier reef of this embayed coast incloses a lagoon, usually a mile or more in width; but the Navua and Rewa rivers have

formed deltas, well shown on charts in Agassiz' Fiji report (1899, plates 5, 6), that have not only filled the embayments in which the rivers must have mouthed when the last submergence took place, but have advanced so as to narrow and shoal the lagoon. Many fringing reefs must have been smothered under the widening front of the advancing deltas. The Rewa, the largest river of the island, discharges a great volume of water when in flood; its delta has already covered certain parts of the barrier reef, and has converted the narrow lagoon, ordinarily 15 or 20 fathoms deep, into shallow mud flats for a long-shore distance of 15 miles. A continuance of delta growth, undiminished by future subsidence, may be expected to kill the corals on the outer face of the barrier reef as far as the river muds are spread, and the progradation or retrogradation of the delta front will then depend on the relative strength of the constructive river and the destructive waves.

It is stated above that the "soapstone" strata of the dissected and partly submerged coastal plain of mid-southern Viti Levu rest unconformably on an eroded foundation of resistant volcanic rocks, and this implies that subsidence took place during the deposition of the coastal-plain strata. A coral reef should have been formed during that subsidence, first as a fringe, later as a barrier, and it is highly probably that a reef of this kind was formed during the earlier stages of soapstone deposition; but no such reef is now visible in the soapstone district, although an elevated reef, apparently of "soapstone" age, occurs farther west, where the soapstone is of small thickness or wanting. The elevated reef at Suva, in the soapstone district, is a small affair that was formed and buried as a conformable member of the soapstone series. It is therefore permissible to suppose that the incipient barrier reef, which should have been formed in the earlier stages of soapstone deposition, was smothered and buried in the later stages. This supposition is made the more reasonable when it is recognized that the delta deposits now accumulated within and on the present barrier reef are small in volume compared to that of the soapstone series, and yet they are almost sufficient, near the rivers, to smother the barrier reef of today.

As far as information is at hand, the northwestern side of Viti Levu is not bordered by soapstone strata; and the barrier reef there incloses a vast lagoon, which deepens offshore to nearly 60 fathoms, as has been adverted to above and as will be further noted below. Thus here, as at Vanua Mbalavu, a tilting of the land-mass seems to have accompanied the uplift by which the soapstones were emerged, and the subsidence in response to which the present barrier reef grew up. Changes of ocean level could not determine unequal changes of this kind.

THE HALF-SUBMERGED CLIFFS OF NEW CALEDONIA

If after its broad rock platform and high cliffs had been cut by the waves, the Madras district of southeastern India, block C, figure 14, had subsided beneath the sea, block E, instead of risen from the sea, block D, it might be today fronted by a long barrier reef inclosing a lagoon, the waters of which would lie against the partly submerged cliffs where fringing reefs would thrive and enter many cliff-breaching valleys in the form of branching bays. The amount of the subsidence could not be well measured by the depth of the lagoon, because its floor would be aggraded by an unknown thickness of sediments; still less by the depth of the bays, where river sediments would accumulate; the subsidence could be better measured by the downward prolongation of the bay-side slopes with gradually decreasing declivity, until their intersection marked the bottom of the drowned valley that the bay represents.

As the Madras district was fated to rise, we must go elsewhere for the realization of a similar coast that has subsided; we fortunately find it along the northeast side of New Caledonia, which exhibits all the features just outlined. Much of that side of this long island is cut off in strong cliffs, which, although by no means vertical, still rise 500 or 1,000 feet above sealevel, as in figure 15, although their base line is submerged several hundred feet. The upper view, looking south, shows Thio, a delta-front port at the mouth of an embayed and aggraded valley, from which much nickel ore is shipped; the high cliffs of the outer coast on the left are followed by low cliffs on the spur ends of the valley side, a short distance inland. The second view, also looking south, near the bay of Bâ, illustrates the maturely even alignment of several cliffs that truncate the spur ends of the dissected highlands. The third and fourth views are of a strongly truncated promontory between Laugier and Kuaua bays; one shows the face of the cliffs, looking south; the other, looking southeast, gives the profile of the cliffs in strong contrast to the maturely carved forms of subaerial erosion on the east side of Kuaua Bay. In these two views the little vertical cliffs cut by lagoon waves at present sealevel are seen at the apparent base of the great slanting cliffs of earlier origin, the real base of which lies, as well as can be inferred from the slopes of the bay sides, several hundred feet below present sealevel. Singularly enough, these great cliffs are hardly mentioned in the published accounts of New Caledonia; or if mentioned they remain as completely unexplained as the beautiful embayments by which they are interrupted. True, the cascades that here and there leap down the cliff face from small hanging valleys have occasionally excited comment; thus Brenchley noted "a fine water-

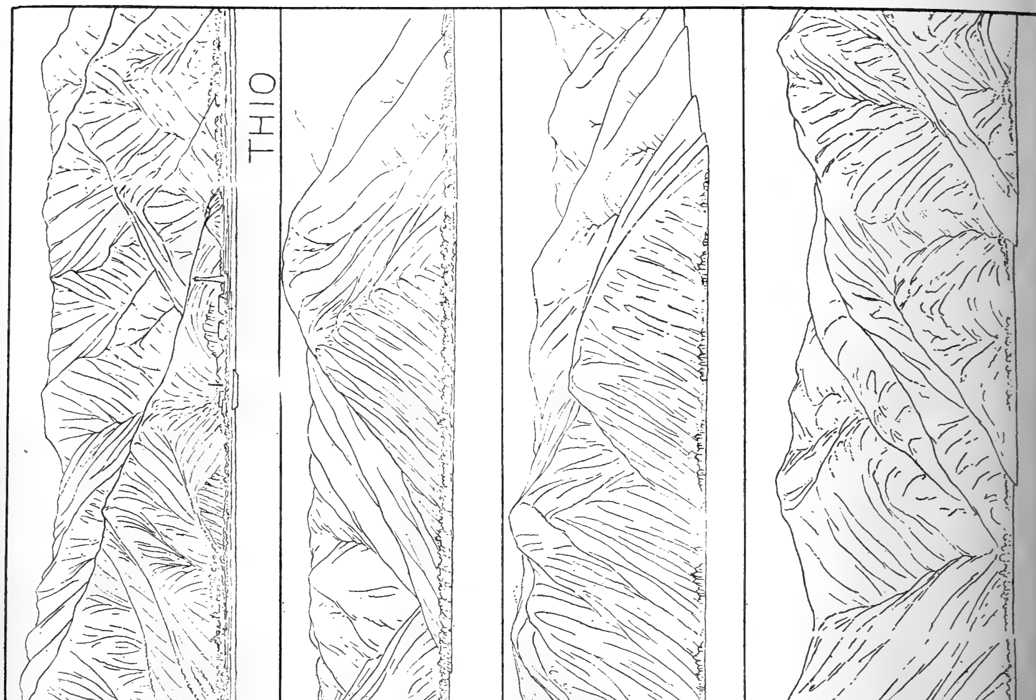

FIGURE 15.—*The clift northeastern Coast of New Caledonia*

fall . . . of considerable height, coming down a channel it had worn for itself on the mountain side, and finally falling over a steep cliff into the sea" (1873, 326); but he went no farther: a cascade on an island rim a simple cascade was to him, and it was nothing more.

It is conceivable that the cliffs of the New Caledonian coast are due to a great fault, but as well as I could judge by careful scrutiny from the deck of a passing steamer and from excursions ashore at several points, no associated step-faults are to be seen in the uplands back of the cliff top, and this suggests that the cliffs were cut by the waves while the island stood higher than now. The cliffs are repeatedly breached by branching embayments, the rock-bottom depth of which was estimated at 600 or 800

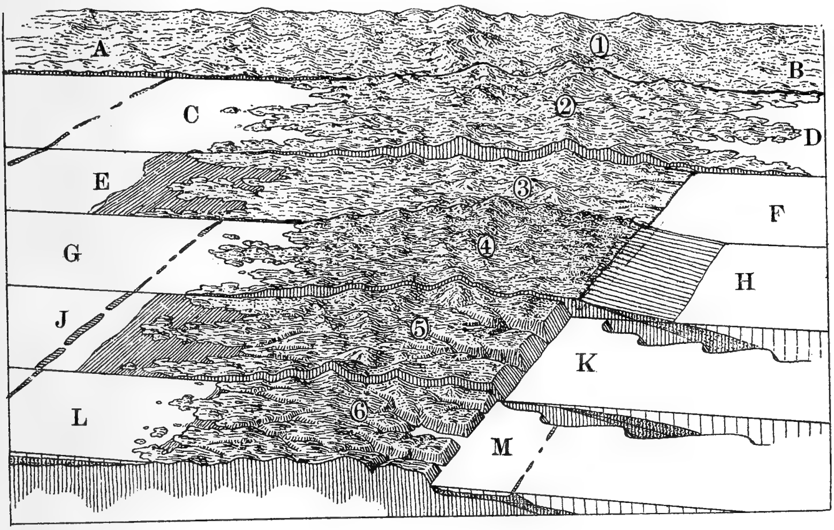

FIGURE 16.—*Evolution of the Coasts and Reefs of New Caledonia*

feet. Thus the total height of the cliffs may be from 1,000 to 1,800 feet. The abraded rock platform in front of the cliffs might well have a breadth of 5 or 10 miles, for the seaward slope of the uplands back of the cliff tops is moderate. Deltas are now filling the bayheads, fringing reefs are growing along the shoreline on the face of the partly submerged cliffs, an imperfect barrier reef rises 5 or 10 miles offshore, and the lagoon has a depth of 30 or 40 fathoms.

In strong contrast with the clift northeastern coast, M, figure 16 (looking west), the southwestern coast of New Caledonia descends with gentle slopes to a greatly embayed shoreline, L, bordered by fringing reefs, except where deltas of the current cycle of erosion prevent coral growth,

and fronted by a superb barrier reef several miles offshore. Cliffs do not seem to have been cut on the southwestern side of the higher-standing land-mass, G, J, during the penultimate cycle of erosion and abrasion, blocks 4, 5, that was occupied by the cutting of great cliffs, K, on the northeastern side and closed by the general subsidence which introduced the present cycle, block 6: hence the penultimate cycle was probably introduced by a flexure of a preexistent island, EF, which caused elevation along the northeast side of the island, H, and depression along the southwest side, G; thus there would have been a reef-free shoreline of emergence along the northeast coast, where cliffs, K, would be cut as long as the island stood still or subsided slowly; and a reef-fronted shoreline of submergence along the southwest coast, where deltas would advance in the bays, while the offshore reefs would grow up and broaden; until the later and more general subsidence of the whole island caused reef upgrowth to the present sealevel, much less continuous on the northeast than on the southwest, but in general extending all around its long oval circuit, a crosswise segment of which is shown in block 6.

Irregular deformation, in which subsidence ultimately dominates, seems indispensable in explaining these various features. The northeastern side of the island, M, finds its best explanation as a recently submerged coast of long previous, H, and long enduring, K, emergence; the recent submergence must be due to subsidence, because it is of greater measure than can be reasonably explained by a rise of ocean level, and it was this subsidence that gave opportunity for the imperfect upgrowth of the present barrier reef. The earlier stages of this scheme are manifestly hypothetical in a high degree, but they have at least the merit of taking account of all that is known of the geology of the island, and of proceeding by reasonable steps from its former subcontinental area, block 1, of unknown extent, AB, through such a series of longer or shorter erosional cycles as will account not only for the present shoreline and reefs, but also for the special features of the uplands and the lowlands that are seen on the two sides of the actual island. The physiographic evidence in support of the successive deformations shown in figure 16 can not be fully given here, but the coherence of the scheme thus graphically represented certainly speaks in its favor and warrants the association of New Caledonia with Tahiti in confirmation of the hypothetical views expressed above as to the probable development of cliffs around many emerged islands during an early reef-free stage of their development.

The upshot of all this chapter is that coasts of recent emergence and coasts of more remote emergence, as well as coasts (except small islands) of remote submergence, do not offer conditions favorable for reef growth;

but that, on the contrary, coasts of recent submergence, and especially coasts of long-continued submergence, offer highly favorable conditions. Hence either a slow rise of the ocean or the slow sinking of a coast will favor the growth of reefs, all the more if the change of level be long continued at not too rapid a rate. But as reef-bordered coasts have suffered submergences of various amounts and dates, frequently associated with neighboring emergences, they can not be accounted for by a universal, uniform, synchronous rise of the ocean, and must therefore be accounted for by local, variable, and non-synchronous subsidences of the coasts concerned; and this conclusion supports Darwin's theory.

Unequal Depths of Lagoons and Banks

THE REQUIREMENTS OF THE GLACIAL-CONTROL THEORY

It is desirable, before the facts as to the depths of lagoons and banks are examined, to define as clearly as possible the unlike requirements regarding them that are demanded by the Glacial-control and the subsidence theories. The Glacial-control theory, as set forth by Daly, recognizes that "there has been Recent crustal warping in certain oceanic areas affected by coral reefs" (1915, 222), but places much greater weight on "a long period of nearly perfect stability for the general ocean floor"; this is clear from the statement: "Most of the reef platforms, like many banks situated outside the coral seas, have such forms, dimensions, and relations to the sealevel that they appear to have originated during a long period of nearly perfect stability for the general ocean floor. . . . That is a conclusion forced on the writer by a close study of the marine charts. Its validity is a matter quite independent of the validity of the Glacial-control theory. . . . Submarine topography seems impossible of explanation without assuming crustal quiet beneath most of the deep sea during at least the later Tertiary and Quaternary periods. The new theory, therefore, is based on the necessity of assuming *general* crustal stability in the coral-sea area during the formation of the existing reefs and platform surfaces" (162).

The theory then postulates a lowering of ocean level by some 30 or 40 fathoms during the Glacial period, the abrasion of platforms by the lowered ocean, and the upgrowth of reefs on the platform margins as the ocean rose to its normal level. Little attention is paid to the replacement of abrasion by reef growth during inter-Glacial epochs; it is stated that "wave abrasion began before the climax of the Kansan stage and continued without serious interruption until the Wisconsin climax" (181); the much longer duration and the somewhat higher temperature of the

last inter-Glacial epoch than of the present post-Glacial epoch are thus set aside; "the sea was actively attacking the islands and continental coasts throughout nearly the *whole* Glacial period. The reef-building corals were largely killed off long before the ice-caps of the first Glacial stage reached their full size" (180); broad platforms were therefore abraded.

In spite of the confidence with which these assertions are made, and notwithstanding the apparent plausibility of the assumption that reef-building corals should have been killed by the temperature of the Glacial ocean, I can not find independent proof that abrasion actually took place as the Glacial-control theory demands. For, as already noted, the spur ends of reef-encircled islands are not clift as they should be if the reefs were killed and if abrasion endured long enough for the truncation of large preglacial islands now supposed to be represented by the Macclesfield and other banks. Nor are they clift as they should be if the shores of such islands were attacked by waves while their now-embayed valleys were deepened, for abrasion by open-ocean waves is a much faster process than valley deepening by small streams and valley widening by subaerial weathering. I have prepared a special discussion of this aspect of the problem in the article on Tahiti, above mentioned, and need not pursue it further here except to note that the rock-resistance of an island does not affect the conclusion reached. For if the embayments of an island are well opened, it follows that stream erosion and subaerial weathering must have had opportunity of working for a long enough period to deepen and open the embayed valleys to their observed form, whatever the resistance of the rocks may be; and hence that during such a period the waves must have had abundant time to cut great cliffs on the island margin. The prevailing absence of such cliffs compels me to believe that the organisms on the flanks of the encircling reefs were not so completely killed as to permit abrasion; the exceptional occurrence of cliffs, as on one side of New Caledonia and all around Tahiti, only serves to emphasize the rule of non-clift shores that elsewhere obtains.

THE EXPECTABLE FORM OF ABRADED PLATFORMS

However, in order to give the fullest consideration to the Glacial-control theory, let it be accepted that abrasion proceeded as therein assumed. As a result, all coasts of continents and islands then exposed to wave-work would have been cut back in platform and cliffs, of dimensions proportionate to the resistance of their rocks, of their exposure to the waves, and of the duration of wave attack. Let the narrowness of abrasion on many reef-encircled islands—such as Kusaie in the Caroline group, where

the spur ends are not clift, although the reef on the east and north is a narrow fringe or close-set barrier, only a quarter or half a mile in width—be overlooked, and the floors of barrier reefs and atoll lagoons and the floors of submarine banks be regarded platforms of abrasion, now more or less covered by postglacial reef growth and sediments. The problem is to determine the features by which the existence of the abraded platforms beneath the aggraded floors can be discovered. A general treatment of this problem has been given by Barrell (1915). I have discussed it in some detail in an article on "Submarine banks and the coral-reef problem" (1918, *a*), and will therefore present here only its leading conclusions.

First, abraded platforms must have a gentle seaward slope; hence a large platform which completely truncates a preglacial island 50 miles or more in diameter should be 20 or 30 fathoms deeper around its margin than at its center; as a whole such a platform should have the form of a very flat cone. Second, the center of a platform of complete truncation and the inner cliff-base margin of an island-benching platform should give the best indication of the level of the sea at the time when abrasion took place. True, the center of a truncating platform might, if abrasion continue long enough, be worn down to a moderate depth below the level of the abrading waves, but the inner margin of an island-benching platform ought to lie close to the mean sealevel at the time of abrasion. Third, the level of the abrading sea thus recorded ought to be everywhere at about the same depth below present sealevel. Fourth, postglacial aggradation will make the depths of lagoons and banks less than that of the underlying platforms, and the decrease of depth thus caused will be, as Daly has shown, "in indirect proportion to the width of the platform" (1915, 192)[2]; for the smaller the platform the greater the aggrading effect of waste inwashed from the upgrowing reef around its margin. The central area of very large lagoons and banks will be aggraded chiefly by locally formed organic deposits. Fifth, a further consequence of platform abrasion to a fairly uniform depth followed by marginal upgrowth of reefs in a uniformly rising ocean is that barrier and atoll reefs today should be, as a rule, of similar dimensions in cross-section.

It follows that large lagoons and banks will give the best indication of the depth of the (supposed) underlying abraded platforms; that the depths thus found should be less, by reason of their aggradation, than the 30 or 40 fathoms by which the ocean is supposed to have been lowered in the Glacial period; and that depths of barrier-reef lagoons should always

[2] The original statement is misprinted "in direct proportion," and is here corrected with the approval of the author.

be less than 30 or 40 fathoms, unless postglacial subsidence has taken place, or unless the glacial lowering of ocean level was more than 40 fathoms, which seems improbable.

THE REQUIREMENTS OF THE SUBSIDENCE THEORY

It is well, when we attempt to determine the features of lagoons formed according to Darwin's theory, to bear in mind his original statements regarding the fundamental postulate of subsidence. Many statements indicate intermittent movements; thus, "Subsidence supervening after long intervals of rest . . . is probably the ordinary course of events" (1842, 130). Subsidence of different islands at different times is clearly conceived. Recent subsidence is illustrated by Vanikoro, in the Santa Cruz group of the western Pacific, where "the unusual depth of the channel [lagoon] between the shore and the [barrier] reef, the entire absence of islets on the reef, its wall-like structure on the inner side, and the small amount of low alluvial land at the foot of the mountains, all seem to show that this island has not long remained at its present level, with the lagoon channel subjected to the accumulation of sediment, and the reef to the wear and tear of the breakers." More remote subsidence is inferred for the Society Islands, "where . . . the shoalness of the lagoon channels round some of the islands, the number of islets formed on the reefs of others, and the broad belt of low land at the foot of the mountain indicate that, although there must have been great subsidence to have produced the barrier reefs, there has since elapsed a long stationary period" (128). The relation of subsidence to lagoon depth is explicitly stated: "The lagoon channel will be deeper or shallower, in proportion to . . . the accumulation of sediment; . . . also to the rate of subsidence and the length of the intervening stationary periods" (99), and the effect of a long stationary period in nearly filling a lagoon with sediment is mentioned (102).

The effect of unusually rapid subsidence in producing fringing reefs of a new generation, as was so clearly, though briefly, explained by Darwin, has already been sufficiently considered. The effect of rapid subsidence on atolls was more fully stated and has been more generally recognized: "There is nothing improbable in the death . . . from the subsidence being great or sudden, of the corals on the whole, or on portions of some of the atolls. . . . Further subsidence [of a submerged atoll], together with the accumulation of sediment, would often obliterate its atoll-like structure [form?] and leave only a bank with a level surface" (108, 107). Elevation also has its due in Darwin's discussion, as well as oscillations of level (145, 146). In thus accepting the possibility of both

kinds of change of level, the theory of subsidence appears to me more probably correct than the Glacial-control theory, in which, although elevation is accepted wherever high-standing reefs occur, subsidence is regarded as very exceptional. Changes of ocean level were mentioned very briefly by Darwin: the need of combining the oscillations of ocean level during the Glacial period with submergence due to subsidence of reef foundations is, to my mind, the most important contribution of the Glacial-control theory; but, as far as I have been able to interpret the history of coral reefs, oscillations of ocean level have been of less importance than island subsidence. Certain special consequences of intermittent subsidence must next be considered.

THE SMOOTHNESS AND DEPTH OF LAGOON FLOORS

The smoothness of lagoon floors, whatever the form of their buried rock foundation, was ascribed by Darwin to aqueous deposition (26). This finds confirmation in Gardiner's detailed studies of the Maldive lagoons, of which he says: "It is only in a few protected situations, where the depth is as great as 40 fathoms or more, that the lagoon bottom appears not to be churned up by the currents and waves. In heavy weather the lagoon water is almost milky, and floating surface nets are almost useless on account of the enormous amount of mud in suspension. The total amount of mud that passes out of the lagoon in the water is enormous" (1903, 210). My own limited experience in the Pacific included two examples of rough weather—one in Fiji, one off the Queensland coast in the lagoon of the Great Barrier reef—during which the water of inclosed lagoons was turbid with suspended sediments.

It therefore seems reasonable to follow Darwin in this matter and not Wharton, who ascribed the smoothness of lagoon floors, some of which have very uniform depths at 25 fathoms, to abrasion by waves at present sealevel (1897, 392); still less can I follow Daly in saying: "Wharton's choice of the agency which produced the flatness of lagoon floors and of banks seems irresistible. He rightly regarded this flatness as no less than fatal to the Darwin-Dana theory" (1915, 196). The lagoon floors to which Wharton especially referred have, as above noted, depths of about 25 fathoms, and these must, even according to the Glacial-control theory, have been aggraded by postglacial deposits 15 or 20 fathoms in thickness: hence their flatness must be due not to abrasion, but to the even distribution and deposition of sediments by the agitation of the lagoon waters; for this process would, as Darwin perceived, produce a smooth floor, whatever the form of the rock foundation.

The depths of lagoons may vary, according to the subsidence theory,

through a considerable range; but the inwash and the local supply of sediments will tend to lessen the depth that uncounteracted subsidence would bring about. Furthermore, the inwash of sediments from encircling reefs will be, as above noted, more effective in aggrading small lagoons than large ones, in whatever way the reefs are formed. Moreover, the effect of a rapid subsidence in deepening a lagoon will be lessened by the more active inwash over the reef that will then be for a time partly submerged; and conversely the effect of a stationary period in shoaling the lagoon will be lessened by the obstruction to inwash caused by the sand islands which are formed on the broadened reef during such a period. Hence it is reasonable to expect that the average depths of a good number of lagoons, which are divided into classes according to their breadth, should vary in indirect proportion to the lagoon breadth, whether the reefs have been formed by upgrowth during the subsidence of their foundations or by upgrowth in a rising ocean over non-subsiding foundations; but it should also be expected that individual lagoons of the same breadth should, according to the Glacial-control theory, have closely similar depths, while, according to the subsidence theory, their depths might vary through a considerable range.

It may be stated at once that the facts agree better with the latter than with the former expectation: thus Ringgold and North Argo atolls, in the Fiji group, have the same breadth of about 5 nautical miles, although the first is much longer than the second; but the maximum lagoon depth of the first is 48 fathoms, although the breadth of its reef, nearly a mile, suggests a considerable aggradation of the lagoon floor, while the maximum depth of the second is only 21 fathoms. Again, Budd reef, west of Ringgold atoll, in northeastern Fiji, an almost-atoll inclosed by an unusually narrow reef rim, measuring 12 by 6 miles, has a maximum depth of 47 fathoms; two lagoons imperfectly inclosed by barrier reefs near the islands of Rambi and Taviuni, not far to the west of Budd reef, have depths of 47 and 49 fathoms, thus strongly suggesting recent and rapid subsidence; while Ngele Levu, to the northeast, measuring 13 by 7 miles, and therefore a little larger than Budd reef, has a maximum depth of only 10 fathoms; and the maximum depth of the much larger Great Argo atoll, farther south, is no more than 36 fathoms, although it measures 22 by 8 miles in diameter. Other examples of the same nature might be adduced, but lack of space forbids their citation here.

In addition to the examples of atolls of similar breadth and unlike depth, instanced above, the depths of the Maldive lagoons in the northern Indian Ocean west of India have an interest in the present connection. They vary from 20 or 30 fathoms in the northern members to 40 or 48

in the southern members, the over-all distance being 400 nautical miles. Darwin was aware of these facts, yet said in the first edition of his book: "I can assign no adequate cause for this difference of depth" (1842, 34); but in the second edition he added, "excepting that the southern part of the archipelago has subsided to a greater degree or at a quicker rate than the northern part" (1874, 47). No one since Darwin has suggested a more adequate cause. It is interesting to note that the "drowned atoll" known as the Great Chagos bank lies farther south in the same line.

VARIATIONS IN THE DEPTH OF SUBMARINE BANKS

The numerous facts here pertinent must be briefly summarized. The central depths of certain large banks ought, according to the Glacial-control theory, to be of similar measure, and less by the thickness of their aggrading sediments than the 30- or 40-fathom depth of their buried platforms; but according to the subsidence theory, they need show no close accordance. The facts are that while depths of less than 30 or 40 fathoms prevail, certain banks have greater depths: thus the Macclesfield bank in the China Sea has central depths of 45, 55, and 60 fathoms; the Tizard bank, farther south, in the same sea, 48 fathoms; the Vanguard bank, farther southwest, 50 to 57 fathoms; the Saya de Malha bank, a rimless bank in the southern Indian Ocean, has depths up to 64 fathoms; the Great Chagos bank, in the same ocean, is 48 fathoms in depth near the center, though it has a rim of less than 20 or 10 fathoms. A great bank in the Tonga group of the open Pacific slants to a depth of over 50 fathoms.

None of these depths are fairly compatible with the requirements of the Glacial-control theory; still less so, when it is recognized that several of them, like Macclesfield and Great Chagos, have been changed by marginal reef growth and surface aggradation from their supposed initial form of flat cones that abrasion would have given them to their existing form of shallow saucers; and as this change demands a marginal reef-thickness of some 50 fathoms and a decreasing aggradation from rim to center, it must be supposed that a significant thickness of sediments has been laid down over the central area also; hence the depths of 60 and 48 fathoms there measured must be significantly less than the depth of any buried rock platform that may exist beneath. This aspect of the coral-reef problem is more fully treated in another article (1918, *a*).

BANKS AROUND REEF-FREE CLIFT ISLANDS

It may be fairly urged that the amount of lowering of the Glacial ocean ought, as long as it is in doubt, to be independently computed by each

student of the coral-reef problem, and especially by those who question the correctness of the Glacial-control theory, into which the change of ocean level enters as an important factor. While recognizing the propriety of this opinion, I have excused myself from the labor involved in adopting it, because an independent observational test of the general value of ocean lowering seems more desirable than a numerical recalculation of its measure. The desired test is found in the depth of several submarine banks, from the central part of which reefless and clift islands rise.

The survival of the clift central islands proves that the banks are in part at least due to abrasion, and that the truncation of the islands was incomplete. Hence the depth of the rock-floor in such banks at the base of their cliffs would give a good indication of the position of ocean level when their abrasion took place. The rock-floor depth can not be directly determined, because some aggradation of the banks has been accomplished since abrasion ceased. Aggradation from the surviving islands can not, however, be of great amount, because the cliffs still plunge down below the sea surface and are as yet little benched at present sealevel. Whatever aggradation has taken place ought to be less and not greater than the aggradation of reef-rimmed banks, where organic sediments are supplied in relative abundance and where the supplied sediments are largely retained on the saucer-shaped surface.

Now if we examine charts of the banks around Tutuila (Samoa), and especially around the Marquesas Islands, the clift spur ends of which are reef-free though the islands lie near the equator in the eastern Pacific, and also around a number of small and clift residual volcanic islands on the border of the coral seas, such as certain northwestern members of the Hawaiian group, and Norfolk Island between Australia and New Zealand, the depth of the inner, cliff-base margin of the banks is found to be about 20 fathoms, although their outer border may be twice as deep. The aggradation of the extratropical banks, where coral growth is scanty or wanting, is probably less than that of the intertropical banks. Hence if the extratropical banks were cut during the lower stand of the Glacial ocean, the measure of 30 or 40 fathoms given by Daly as the amount of ocean lowering may be taken as liberal, and certainly as not erring in the way of being too small.

Several interesting inferences follow. First, it does not seem possible that the removal of aggrading sediments would bring about an agreement between the smaller depths of the aggraded surface over the undoubted rock platforms around the clift residual islands of the extratropical seas, and the greater depths over the center of the very hypothetical rock plat-

forms of the intertropical banks. The differences of from 30 to 50 fathoms here disclosed between the depths of banks that should, according to the Glacial-control theory, be closely comparable are not easily explained without the aid of unequal subsidence.

Second, the strong cliffs cut in the resistant volcanic rocks of the central islands on these reefless extratropical banks show that the waves of the lowered ocean, which abraded the platform around these islands, were abundantly capable of cliffing the intertropical volcanic islands, now surrounded by fringing or by close-set barrier reefs, provided the reef-building organisms were killed while the ocean was lowered; and as those islands are not clift, we find here again reason for rejecting the assumption that the reefs were dead. We are thus fortified in the conclusion, which may have been lost sight of by the reader during the discussion of the possible truncation of the Macclesfield and other banks on earlier pages, that submarine banks can not be the result of abrasion and in the associated belief that their present unequal depths are due to subsidence.

Third, the considerable extent of some of the banks on the border of the coral seas—the bank around Norfolk Island measures 55 by 20 miles in extent and the banks around some of the northwestern members of the Hawaiian group are of similar dimensions—makes it improbable that they are due chiefly to the abrasion of still-standing volcanic islands by the lowered Glacial ocean; and the record of "coral" in some of the soundings suggests that part of the banks may be made of reefs. It is therefore worth considering whether these banks may not have been inclosed by extensive barrier reefs during the last inter-Glacial epoch, which is believed on good grounds to have been warmer and longer than the present post-Glacial epoch; for, if so, we should most appropriately have here, on the border of the present coral seas, precisely the consequences deducible from the Glacial-control theory, including the cliffing of central islands as well as the truncation of reefs; and in the association here of those two elements we should have proof that the theory does not apply within the coral seas of today, where clift central islands are of rare occurrence.

Fourth, the depths of about 40 fathoms, which characterize the outer margin of the extratropical banks above named, are, like similar marginal depths elsewhere, in my opinion more reasonably explained as the result of wave and current agencies working on loose sediments with respect to present sealevel than as a mark of any former lower level of the sea; for the various indications of recent upheavals and subsidences found in other islands, such as Oahu and New Zealand, not far from the banks in question, make it altogether improbable that the banks have long been stationary; and if they have moved either up or down, some agencies such

as those above suggested must have since then been in operation in order here to develop marginal depths that so well accord with the marginal depths which are elsewhere believed to be the work of those agencies.

THE DEPTH OF BARRIER-REEF LAGOONS

The greater depths than 40 fathoms discovered in certain barrier-reef lagoons appear to be beyond explanation by the Glacial-control theory, while they are perfectly expectable under the subsidence theory. Depths of 80 or 90 fathoms on the eastern part of the great barrier reef that incloses the Exploring Isles in eastern Fiji have already been mentioned as indicating a recent slanting subsidence of that district, which is confirmed by finding recently elevated reefs to the southwest. The gradual increase in depth to the exceptional measure of 56 fathoms, with a strong probability of greater depths in the uncharted area of the lagoon northwest of Viti Levu, the largest island in Fiji, is especially significant because of the gradual submergence of the accompanying barrier reef, as is well shown on a chart in Agassiz' Fiji report (1899, plate 3). The two features together strongly suggest a slanting subsidence; and for this again confirmation is found by the occurrence of moderately elevated reefs on the southern, but not on the northern, side of this large island. Additional confirmation for the occurrence of slanting subsidence may be found in the southwestward increase of depth, well shown on the charts of a great bank in the Tonga group, above mentioned, to which Daly refers (1916, 208); in the visible slant of the uplifted coral island of Salayer, south of Celebes, as described by Weber (1902, 87); in the slant of Tinian Island in the Mariana group, as described by Seidel (1914); in the slanting emergence of half of the atoll of Uvea, in the Loyalty Islands, of which I had a good view in 1914, and in the presence of uplifted reefs in the southern part of the Pelew group and of sealevel reefs in the northern part, which strongly indicate the emergence of one area and the submergence of the other, in spite of Semper's opinion long ago expressed to the contrary.

The depth of 60 fathoms at mid-length of the imperfectly inclosed bank or platform on the west side of Palawan, in the Philippines, in contrast to smaller depths at its southern end, has been instanced above in evidence of a warping subsidence; here the movement must have been more rapid and more recent than the slanting subsidence in eastern Fiji, because the bank is bordered only by a very imperfect and discontinuous reef rim, and because the fringing reefs of middle Palawan are unusually narrow or wanting. Depths of from 60 to 70 fathoms are recorded in the lagoon of Vanikoro, in the Santa Cruz group, where many other soundings

reached 45 fathoms and no bottom. A depth of 105 meters, or 57 fathoms, is given in the latest German chart of the great lagoon of Truk, in the western Carolines. A depth of 60 fathoms occurs well inward from the margin of a bank or platform that surrounds the often-cited island of Fauro, figure 11, in the Solomon group, and a depth of 58 fathoms is recorded in a space inclosed between Fauro and several smaller islands; this strongly suggests that recent subsidence of Fauro has taken place. It may be inferred also that the subsidence was rapid because there is no barrier reef around most of the bank margin and only a narrow unconformable fringing reef on Fauro itself.

The "sunken barriers" of New Guinea are strongly indicative of unequal subsidence. One such example occurs off the eastern part of the south coast, where the normal barrier reef, which incloses a lagoon from 7 to 20 miles in width and from 40 to 50 fathoms in depth, is replaced for a long stretch by a submerged reef at a depth of 5 or 10 fathoms. Again, east of New Guinea, a large barrier reef incloses a lagoon that measures 115 miles in length by 27 miles in width, and from 30 to 45 fathoms in depth, within which rise the large island of Tagula, 40 by 8 miles in diameter and 2,645 feet in height, and many smaller islands; the southwestern part of this barrier is submerged to depths of 6 or 8 fathoms for a distance of 15 miles. Only 13 miles to the north of this fine barrier system, and separated from it by sea depths of 700 or 900 fathoms, stands Misima, 22 miles long and 3,400 feet high, with no sea-level reefs around it, though Jack and Etheridge briefly mention an island of that name in their account of New Guinea as bearing elevated reefs. Differential movements seem essential here. The same is true of the Solomon group, where, in addition to the submerged platform of Fauro, above mentioned, submerged and emerged reefs occur in abundance.

It may of course be urged that New Guinea and the Solomon Islands, being far removed from the atoll region of the central Pacific, do not afford evidence of the conditions under which atolls have been formed: but in reply it may be stated, first, that barrier reefs and their lagoons, which are largely developed around New Guinea and the Solomons, resemble atoll reefs and their lagoons too closely to ascribe them to unlike processes of origin; and second, that atolls, though rare in the western as compared with the central Pacific, nevertheless occur there in significant numbers. Thus 170 miles north of the Solomon Islands the exceptionally large atoll of Ongtong-Java has a diameter of about 70 miles, and Tasman atoll, about 10 miles; and 120 miles to the south, Rennell Island, an uplifted atoll, has a length of 50 miles. Woodford has given accounts (1909,

1916) of the first and last of the three. If these atolls were formed in the neighborhood of so unstable an archipelago as the Solomons, it can hardly be assumed that the atolls of the central Pacific need a long period of nearly perfect stability for their production. The same argument may be based on the atolls of the China Sea, in the neighborhood of the unstable Philippines.

THE VOLUME OF REEFS

The expectation of similarity in the cross-section dimensions of barrier and atoll reefs that follows from the Glacial-control theory is not so well confirmed by the facts as the opposite expectation that follows from the subsidence theory. Some reefs, like those of Borabora, in the Society group, are broad; others, like those of Budd reef, in northeastern Fiji, are narrow; still others, like those which rim several banks north of Fiji, do not reach sealevel, although their location provides as good opportunity for upgrowth as is provided in Fiji for more successful reefs; and some submerged banks have no reef rims, although their situation seems as favorable for reef growth as that of neighboring rimmed banks. Great variations in the breadth of fringing reefs, from almost zero to three miles, may also be pointed out, but as this subject is more fully treated in the forthcoming article in Journal of Geology (1918, *a*) it need not be further pursued here.

Allusion may be here made to the assumption included in the Glacial-control theory that a truncated volcanic island, lying at a depth of about 30 or 40 fathoms, should serve as the foundation for sealevel atolls; but a number of uplifted and deeply dissected limestone islands in eastern Fiji, which appear to have been atolls originally, give no indication of possessing such platforms, as I have lately shown elsewhere (1917, *a*).

CONTRASTS OF THE CENTRAL AND THE WESTERN PACIFIC

Several writers have called attention to certain contrasts between the central and the western areas of the Pacific. The central and truly oceanic area gives few indications of recent upheaval in the way of elevated reefs, and few indications of rapid subsidence in the way of drowned atolls, although atolls at sealevel are abundant and barrier reefs are numerous. The western area, largely occupied by archipelagoes, gives innumerable indications of recent, rapid, and great upheavals and subsidences, in the way of displaced and deformed marine formations of various kinds, including coral reefs now at altitudes and at depths of 2,000 feet or more. High-standing coral reefs are well known on various islands of the archi-

pelagoes; deeply submerged reefs are less known, but they appear to be well certified in two cases.

A deeply submerged coral deposit was discovered by the Dutch "Siboga" expedition in the Ceram Sea, west of New Guinea, in 1900, where a dredging brought up large quantities of recent reef-building corals, coated with manganese, from depths of from 1,633 to 1,304 meters, at a distance of 42 kilometers from the nearest sealevel reef (Weber, 1902, 80). Molengraaff, who has lately called attention to this extraordinary record, describes the Ceram Sea as occupying "one of the most remarkable trough-shaped deep basins in the eastern part of the Indian archipelago, the origin of which is probably connected with crust movements in Pleistocene and post-Pleistocene times. They were formed by downward movements, simultaneous with and more or less compensated by elevations of about equal amount of other parts—nowadays highly elevated islands—in that region" (1916, 624). Another case is that of the terraced island of Sumbawa, east of Java, recently described by Elbert. This volcanic island not only bears marks of emerged wave-cut benches up to 1,200 meters, and of fringing coral reefs up to 605 meters, but also of submerged reef benches at several levels down to a depth of 463 meters. There can be little question that further exploration of the deep basins within the archipelagoes will bring forth facts of extraordinary interest.

AVERAGE AND INDIVIDUAL VALUES OF LAGOON DEPTHS

Many other citations might be made in further evidence of the contrast here considered: thus great, long-continued, and slow subsidence of the vast oceanic area is indicated by Pilsbry's researches on the land snails of many mid-Pacific islands, which he has briefly summarized in a recent article (1916), and by Crampton's detailed studies of the land snails of the Society Islands (1916), while the geologically frequent alternations of subsidence and upheavals in the western area are emphasized by Schuchert, who concludes, on the basis of elaborate geological studies, that "the entire western half of the Pacific bottom, and especially the Australasian region, appears to be as mobile as any of the continents of the northern hemisphere, with the difference that the sum of the continental movements is upwards, while that of the ocean bottom is downwards" (1916, 105).

In consideration of all this, it would seem prudent for those who adopt the Glacial-control theory of coral reefs to limit its application, in so far as it assumes long-continued stability of the ocean floor, to the central area of the Pacific Ocean, where most of the islands are atolls, in explanation of which the theory seems to have been originally devised, and to

account for the reefs of the unstable western Pacific in some other way, But in Daly's exposition of the theory the tables of depths for reefs and banks, by averages from which the theory is thought to be strongly supported, include examples from Fiji, New Caledonia, Queensland, the Solomon Islands, and the China Sea, as if the reefs of these regions had developed under the same conditions of long enduring stability as those of the mid-Pacific. The Macclesfield bank, in the last-named area, is in particular mentioned on several pages as if, in spite of excessive depth of 49 fathoms in the central part of its aggraded floor, and notwithstanding its nearness to the greatly disturbed region of the Australasian archipelagoes, it still supported a theory in which long enduring stability is an essential postulate and in which the lowering of the abrading ocean, though liberally estimated, is placed between 27 and 33 fathoms; for although uplift or subsidence is not regarded as impossible in the areas studied, it is said to be "necessarily slight." The reasons already adduced for regarding the China Sea as a region of instability appear to me sufficient to invalidate the explanation of the Macclesfield banks and its neighbors by the Glacial-control theory.

In view of the abundant evidence of instability in the region of the Australasian archipelagoes, including that furnished by the unconformable fringing reefs of the Philippines, as above stated, and in view of the reasonable explanation for decrease of lagoon depth with decrease of atoll diameter that is furnished by the subsidence theory as well as by the Glacial-control theory, and again in view of the large departures of individual depth values from average values, precisely as the subsidence theory, but not the Glacial-control theory, would lead us to expect, I am constrained to believe that the statistical argument advanced by Daly for the stability of reef foundations, based on average depths of lagoon and banks, must be misleading. Indeed, the argument may have to be turned the other way round; for if the mean values of the individually discordant depths of atoll lagoons and submarine banks in areas that are independently proved to have suffered frequent and recent movements of upheaval and subsidence, nevertheless accord with mean-depth values for atoll lagoons in the mid-Pacific region, it must be concluded that mean depth values are no safer indication of stability in the latter areas of unknown behavior than they are in the former areas of known disturbance.

The detailed Form of Island Spur Ends as Evidence for intermittent Subsidence

A section may here be given to certain minor features of many reef-encircled island to which attention has seldom if ever been called, al-

though they appear to afford good evidence for relatively rapid subsidence followed by a stationary period, as Darwin thought was probable, rather than for the slow and gradually ceasing rise of ocean level that inheres in the Glacial-control theory. The features referred to are the small rock platforms backed with low bluffs, the work of lagoon waves at present sealevel on the spur ends of dissected islands within barrier reefs, as already illustrated in figure 8 and in the lower views of figure 15. They are here shown on a larger scale in figure 17 (fringing reefs are omitted from the submerged slope to make the diagram more legible).

The significant point is that the outer margin, B, of the visible rock platform, AB, usually lies in the prolongation of the spur profile, FL;

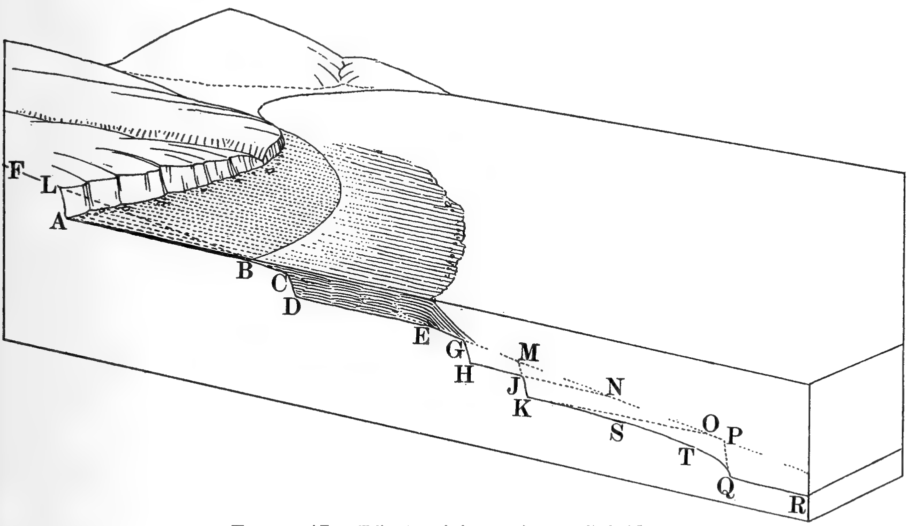

FIGURE 17.—*Effects of intermittent Subsidence*

this means that the bluff, DC, of any similar platform, ED, cut at a lower level, was not worn so far back as B. Hence a submergence of greater measure than the height of the former bluff, DC, must have brought the island to its present position with respect to sealevel; and the submergence must have been so rapid that, while it was in progress, no considerable amount of abrasion was accomplished on the slope CB. For if the measure of submergence, KJ, were less than the height of a previously abraded bluff, KM, then the platform, JH, cut after such a submergence, could not extend forward to N in the line CGM, prolonged from FL; and if the submergence that caused the change of level from QR to KO were slow and ended gradually, then instead of having a part of the normal slope, OP, preserved between a submerged cliff top, P, and the outer

margin of a full-width platform, KO, the slope would be worn during the slow submergence into the curve, QTSK, and the next abraded platform would have small width, near K, and a vague margin toward S.

It is of course eminently possible that unduly narrow platforms, like JH, and worn-off slopes, like ST, may have formerly been abraded at times of small or slow submergence; but the many examples of full-width platforms, BA, that I saw on various islands in the Fiji group, on both sides of New Caledonia, on small islands in the lagoon of the Great Barrier reef of Australia, and on some of the Society Islands, suggest that submerged platforms, DE, are full-width like the visible platforms, AB, and that a submergence of 10, 20, or 30 feet has usually been accomplished in a relatively short-time interval between longer stationary periods. This appears to be better accounted for by intermittent subsidence than by climatic fluctuations of ocean level. In any case the present relation of ocean surface and island level appears usually to have been assumed by a relatively rapid advance of the sea on the land, sufficient to drown any earlier bluff, DC, corresponding to the present bluff, AL.

It is therefore probable that such a change of level would submerge any preexistent barrier reef (not drawn in figure 17) and transform it for a time into a "sunken barrier," similar to the sunken barriers of New Guinea; and that while it was submerged the waves of the lagoon were strengthened by so much of the exterior waves as could cross the barrier. The greater part of the spur-end platform and bluffs may have been then cut before protecting fringing reefs were formed on the new shoreline. Since the barrier reef has again grown up to sealevel and the fringing reefs have broadened in front of the spur ends, wave-work on the platforms and bluffs must have been weakened. The lagoon waves are, however, still strong enough to lift coral blocks onto the margin of the fringing reef and to wash the platform fairly clean, leaving only patches of gravel on its surface and occasional large rock blocks near the cliff base.

The Origin of Atolls

Indirect Evidence from Barrier Reefs

This article has been given the title, "The Subsidence of Reef-encircled Islands," because it is devoted chiefly to the behavior, as to elevation or subsidence, of islands that are bordered by fringing reefs or inclosed within barrier reefs. As far as such islands and the reefs around them are concerned, the various lines of evidence given on the preceding pages appear to me to warrant the acceptance of Darwin's theory of intermittent subsidence as superior to all its competitors; and in so far as the theory is

thus substantiated, it may be regarded as giving the best explanation of atolls as well as of barrier reefs and unconformable fringing reefs, particularly if the atolls are near barrier-reef islands, as in examples that I have described in Fiji (1916, *b*). But it is well to recognize that, as far as isolated atolls are concerned, this proof of their origin is indirect and not compulsory. There are no means of making the proof more direct, apart from expensive borings, such as those on Funafuti, in the Pacific, and Bermuda, in the Atlantic, the results of which may be briefly reviewed.

THE FUNAFUTI BORING

In 1898 the Royal Society of London sent an expedition to Funafuti, an atoll of about 7 miles diameter, in the Ellice group of the equatorial Pacific, and a boring made the year before in the reef to a depth of 698 feet, under the direction of Professor David, of Sydney, New South Wales, was continued to a total depth of 1,114 feet. As the boring was in the reef rim of the atoll, and as the depth reached was only about one-thirtieth of the atoll diameter, or about one-twelfth of the neighboring ocean depths, it is not surprising that no volcanic rock was reached. The limestone core was minutely studied by specialists; but as their published reports (1904) were limited to matters of fact, the principal object of the expedition, namely, a determination of the origin of the atoll, on which these specialists must inevitably have formed well based opinions, was left to the readers of the report for settlement by such inferences as they might be able to draw. Many readers, recognizing that they could not possibly acquaint themselves with the facts of the case as thoroughly as the specialists had done, did not attempt to make a thorough analysis of the report; and the origin of atolls was therefore much less illuminated by this expedition than it would have been if the investigating specialists had been permitted to state their conclusions.

It is only in other publications that the conclusions legitimately derived from the Funafuti borings have been announced by the investigators; for example, by Sollas in his general work on "The Age of the Earth" (19—, 121-132). An excellent summary of the permissible conclusions has lately been presented by Skeats, who introduces them with the following statement: "The significance of the evidence made available by the publication of the very detailed and exhaustive examination of the Funafuti bores appears to have escaped many workers on coral-reef problems or to have been misunderstood. This no doubt is partly to be attributed to the circumstance that the committee responsible for the work consisted of adherents of diverse views on atoll formation, and decided

that the experts to whom the material was submitted should publish descriptions of the material, but should draw no conclusions from the facts as to the mode of formation of the atoll. The writer believes that he is correct in stating that these experts were unanimous in their views that the published descriptions supported Darwin's subsidence theory, and in fact were fairly susceptible of no other known explanation" (1918, *a*, 86). It is also very properly pointed out that "if any part of the bore represented material fallen from above," as must have been the case had the atoll been formed by outward growth on its own talus, according to Murray's theory, "an admixture of shallow and deep water forms must have occurred. Not a trace of deep-water forms was found in the lower or in any other part of the Funafuti bore" (88). The organisms found in the bore are still flourishing in the surface reef or in the lagoon. Skeats' argument for subsidence, based on the dolomitization of reef limestones (1918, *b*), deserves special attention. In view of all this, it seems fully warranted to regard Funafuti as having been formed by upgrowth during the slow subsidence of its foundation, and therefore as confirming Darwin's theory.

THE BERMUDA BORING

A deep boring in Bermuda was reported upon four years ago by Pirsson. It penetrated the island to a depth of 1,413 feet from a point 135 feet above sealevel. The first 380 feet were in limestone; fragmental volcanic material, much altered, as if by subaerial oxidation, was then encountered 245 feet below sealevel, and continued for 210 feet; this was followed by 105 feet of water-worn volcanic sand and gravel; then at a depth of 560 feet below sealevel solid lava began and continued to the bottom, except that "a bed of [volcanic] sand . . . which had been worn upon a beach" (1914, 197) was passed through from 910 to 940 feet below sealevel, or more than 300 feet below the solid volcanic rock. It is inferred that "Bermuda was once an island, composed of volcanic rocks rising above the level of the sea, which has been entirely cut away by the action of the waves" (199); the island is represented in a diagram evenly truncated at the depth at which the weathered fragmental volcanic rock was first reached. "The present depth of water over the different [truncated] banks and the extent to which the bore penetrates before passing through the limestones into water-worn debris seems to indicate a change in water level of perhaps 200 feet since the time when the waves were attacking the coastline of the former island" (204). Subsidence seems to be excluded; for, "provided that one believes in the permanence of the deep ocean basins, it is clear that volcanoes situated on their floors, after

they had been cut down to sealevel, if they once projected above it, would be protected from further erosion and would remain indefinitely as protuberant masses. . . . If such masses have once been brought down to sealevel and continue to exist, and that level [of the sea surface] changes within limits from time to time by warpings in different places of the sea-floor, or by an accumulation of ice on the lands and its melting . . . conditions of shallow water over them may be established suitable for their colonization by those organisms concerned in the production of the so-called coral reefs. . . . It appears to the writer that what has been learned regarding the history of the Bermuda volcano has an important bearing on the question of the way in which the platforms on which coral islands, barrier reefs, and atolls are situated, have been formed. . . . Provided the volcanic masses are of sufficient antiquity, they may, even though of great size, have been reduced to sealevel, furnishing platforms of wide extent. . . . Such masses . . . would continue to project from the ocean abysses indefinitely and many of them may be of great geologic age. There is nothing in the mere size of any of the atolls of the Pacific which would preclude their being placed on the stumps of former volcanic masses" (206). In a word, Wharton's theory of truncated volcanic islands as atoll foundations is here revived, though Wharton is not mentioned; the only significant addition is the assumption of a rise of sealevel as a means of submerging the truncated island.

The difficulty that I find in accepting Pirsson's conclusions arises chiefly from the lack of consideration that has been given to alternate hypotheses other than the one here adopted. In the first place, it must be manifest that a single boring gives no sufficient proof that the volcanic foundation of the Bermuda limestones is a level surface of marine truncation. The foundation may evidently be a volcanic mountain top made uneven by subaerial erosion, while weathered detritus was washed from it and deposited on its flanks beneath sealevel; if so, it is very improbable that a chance boring should strike the highest point: volcanic rock may well underlie Bermuda at a less depth than 245 feet; until additional borings are made, this possibility can not be excluded. Similarly, the assumption that the island was formerly unprotected by reefs long enough for its complete truncation by waves is not made necessary by any of the facts announced; the island may have been surrounded by reefs for a long period, and whatever degradation it suffered may have been chiefly due to subaerial erosion. A long-enduring stability of the island may, of course, be postulated and the consequences of such stability may be deduced; but the instability of the island may also be postulated; surely such instability is not inconsistent with the permanence of ocean basins. Dana believed

in both these doctrines. Indeed, such instability is involved in the suggestion above quoted, that the level of the sea "changes within limits from time to time by warpings in different places of the sea-floor," although it is easily shown that a change of sealevel by 200 feet as a result of such warpings demands a vertical movement as many times greater than 200 feet as the upwarped area is smaller than the total area of the ocean, and is therefore a very extravagant method of submerging an island as compared with the local subsidence of the island itself.

The 30-foot bed of beach sand at from 910 to 940 feet can be accounted for as having been water-worn at sealevel *in situ* during a lull in volcanic activity, then buried under lava flows when eruptions began again, and lowered by subsidence to its present depth; this is quite as reasonable as to suppose that the sand was washed from the beach on which it was worn 700 feet or more down a submarine volcanic slope, during a lull in volcanic activity, and then buried by new lava flows. If it be accepted that barrier and atoll reefs rest on platforms of independent origin, then the truncation of still-standing volcanic islands—if such islands exist—would produce platforms of the desired shape; but it has not yet been shown that barrier and atoll reefs do rest on such platforms. None of the elevated reefs in the Pacific have been found to lie on flat volcanic foundations; wherever the foundation has been examined, it has a slope such as would be produced by subaerial erosion and not by marine abrasion. If we are to learn about one island by studying others, it seems more reasonable to regard the submerged volcanic foundation of the Bermuda limestones as an eroded volcanic mountain, like the visible volcanic foundations of many uplifted reefs in the Pacific, rather than to regard the submerged foundations of the many Pacific atolls as truncated volcanic platforms, because that has been inferred, on the evidence of a single boring, to be the form of the submerged foundation beneath the Bermuda limestones.

DEPTHS OF ATOLL LAGOONS

Two other considerations regarding the atolls of the Pacific deserve mention. It is, in the first place, desirable to point out that no very well assured conclusions can now be drawn from the average depth of atoll lagoons, because the greater number of atolls in the Pacific are at present so incompletely surveyed that the depths of their lagoons are not well known. The international collection of charts in the Hydrographic Office at Washington, in which the latest issues from all countries are accessible, does not afford full details as to depth of lagoons in the atolls of the eastern Carolines, the Marshall, or the Paumotu group. It is therefore

premature at present to express a definite opinion as to the evidence for or against subsidence that their lagoon depths may hereafter furnish; but in view of what has been intimated above as to the less disturbed history of the central Pacific area than of its western part, and in view of the scarcity of submerged banks in the central area, it may be expected that excessive depths will not be found, even in the lagoons of the largest atolls, and that the lagoon depths will, as a rule, vary in indirect proportion to the diameter of the atoll, for reasons above noted.

In other words, prevalent submergence resulting from intermittent subsidence, compounded with Glacial changes of sealevel, as a result of which the majority of central Pacific atolls seem to have been formed, has apparently been, as Darwin assumed (115), not faster and frequently slower than the upgrowth of coral reefs. Nevertheless, the large almost-atoll of Truk, in the western Carolines, has lagoon depths of 57 fathoms, and the almost-atoll of Mangareva, which includes the Gambier Islands, south of the Paumotus, has depths up to 43 fathoms within the polygonal space inclosed by its small volcanic islands, where abrasion could not act effectively; both of these measures, but especially the first, must be difficult of explanation by abrasion, when the ocean was lowered less than 40 fathoms.

REGIONAL OR LOCAL SUBSIDENCE

The second consideration is that no compulsion inheres in the argument against Darwin's theory, based on the prevailing absence of coasts of emergence backed by young coastal plains around continental borders; for while it is true that a broad subsidence of the central Pacific floor by some such measures as 1,000, 3,000, or 5,000 feet would cause the emergence of continental margins by a quarter or less of those measures wherever the continental borders themselves did not subside, and while it is also true that Darwin inferred such measures of Pacific subsidence in explanation of the many atolls in that ocean, it is not true that such subsidence is essential to his theory. A local subsidence of reef foundations will serve, as far as reef upgrowth is concerned, fully as well as a widespread subsidence of the ocean floor. Not only so, if most coral reefs—apart from those of the western Pacific archipelagoes—are based on oceanic volcanoes, as seems highly probable, and if the local subsidence of such volcanoes on an otherwise stable ocean floor is the prime factor in determining the upgrowth of their reefs and the transformation of original fringing reefs into barrier reefs and atolls, then it may be shown that, after a long period of oceanic eruptions, subsidences, and reef growths, the ocean surface would be not lower, but somewhat higher, than

before, and the continents would be characterized rather by the predominance of coasts of submergence, as they really are, than of coasts of emergence.

For if many lofty volcanic cones are successively built up on the ocean floor, the ocean surface must be thereby somewhat raised; and if, as the cones successively subside, their place is largely taken by an atoll crown, the ocean surface will retain its rise instead of sinking again, as I have recently shown elsewhere (1917, *b*). [Here be it noted that the withdrawal of limestone from solution in water diminishes the water volume by only a small fraction of the volume of the withdrawn limestone.] Hence, as far as the prevalence of coasts of submergence around continental borders is concerned, they testify in favor of the local subsidence of volcanic islands which are locally reconstituted by reef growth as they subside, and against a broad subsidence of the ocean bottom, the effects of which could not be compensated by reef growth. It is true that geological opinion has usually been in favor of regarding volcanoes as situated in areas of elevation, and that active volcanoes in particular have been usually regarded as rising, not sinking; but the opposite opinion deserves consideration.

The well supported interpretation given by Branner (1903) to the great canyons in the northeastern part of the island of Hawaii carries with it the implication that that great volcanic mass has been subsiding during the later stages of its eruptive activity at least. Similarly, the relation of the partly submerged valleys in the older (western) and younger (eastern) parts of the Oahu volcanic doublet gives strong indication that the subsidence of that island, which now amounts to 1,000 feet at least, had begun before its volcanic activity ceased. Taviuni, in northeastern Fiji, bears several young volcanic cones, yet near by are several deeply dissected volcanic islands, the embayed shorelines of which indicate a recent subsidence of several hundred feet. Kandavu, a larger island in southwestern Fiji, has a young volcanic cone, little dissected, near its western end; the rest of the island is maturely dissected and elaborately embayed, as if it had recently suffered strong subsidence.

Besides these islands which bear recently active volcanoes there are numerous other volcanic islands so old that they have been deeply dissected; but these also have been shown, by various lines of evidence already set forth, to have subsided, namely, by the rock-bottom depth of their embayed valleys, which is frequently much greater than the Glacial lowering of sealevel; by the thickness of their encircling reefs as measured up from the submarine prolongation of the island slopes; by the unconformable contacts of reef limestones on the eroded spurs; and by

the disappearance of the detritus that has been eroded from them. We are thus led toward a favorable consideration of an idea that marks a new advance in the discussion of the origin of coral reefs.

Molengraaff's Views as to the local Subsidence of volcanic Islands

Theoretical considerations in favor of a greater or less subsidence of volcanic islands have been stated by Gerland (1894, 56) and Daly (1914, 186); but the most definite utterance on this subject is to be found in a recent paper by Molengraaff (1916), from which several citations have already been made above. This experienced author points out that oceanic volcanic islands "are not isostatically compensated and, without exception, show a larger or smaller positive anomaly of gravity. . . . On account of isostasy itself, these volcanic islands, rising . . . as cones or groups of cones of considerable bulk, can not always remain in existence; under the influence of gravity they will without exception yield and sink down slowly, but gradually, and if this movement is not counteracted by other forces they must disappear below the sea and finally approach more and more the form of the ocean bed. . . . It appears to me that the yielding and slow sinking of the volcanic islands under the influence of gravity must be regarded as the cause of the downward movement of large amount and long duration which must be assumed in order to explain the formation of barrier reefs and atolls in true oceanic regions, the cause of which had as yet not been ascertained" (1916, 619, 620).

It would not promote the solution of the coral-reef problem to insist that this ingenious idea is wholly correct; one may conceive that the subsidence of volcanic islands may have more to do with the weakening of the internal force that caused their eruptive growth than with their excessive density. Be this as it may, the general idea here advanced is pertinent and helpful. In so far as we may trust the argument given above, from which it appears that the prevalence of shorelines of submergence on continental coasts is more consistent with the local subsidence of reef-bearing islands than with the broad subsidence of the Pacific Ocean bottom, Molengraaff's suggestion is supported. It is supported also by the contrast between the long enduring subsidence of reef-formations that appears to characterize the central Pacific area and the many irregular disturbances of the western archipelagoes. But in thus favorably regarding the possibility of relatively local subsidence of volcanic islands, deformation should not be wholly excluded from the central area of the Pacific; the great flexure of the Kermadec-Tonga region, the uplifted reefs of Oahu, and

the occasional uplifted atolls elsewhere in the open ocean suffice to prove that other processes than isostatic subsidence must be considered. Be that as it may, the plausible possibility that volcanic islands may locally subside, as if isostatically, is a most important contribution to the coral-reef problem; this may, indeed, be the law for which it was said long ago, "the isles shall wait." As far as its principle proves to be valid, it will strongly supplement the several lines of independent evidence given on the foregoing pages in favor of Darwin's theory of upgrowing reefs on subsiding foundations, although it discredits the broad application of his theory to great areas of the ocean floor.

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AGES OF PENEPLAINS OF THE APPALACHIAN PROVINCE [1]

BY EUGENE WESLEY SHAW

(Presented before the Society December 27, 1916)

CONTENTS

PROBLEM

The wide acceptance and use of inferences concerning the presence and approximate age of the peneplains, covering in the aggregate almost all of the Appalachian Highlands, make the dating of these peneplains a matter of great interest and importance in deciphering the history of the region and in interpreting the sedimentary deposits derived therefrom. Great precision may perhaps never be possible; but on account of the importance of the problem, it seems desirable to examine the data which have been set forth and to add to them if possible. In this paper it is proposed to accept Appalachian peneplains as they are described and to consider them in the light of certain general principles and of published and unpublished data concerning buried peneplains in the Atlantic and Gulf coastal plains. No inferences except those relating to age are discussed, and the proposed modifications are to be regarded only as suggestions.

METHODS OF DETERMINING DATE OF COMPLETION OF A PENEPLAIN

Apparently the principal lines of attack for determining the time of formation of a peneplain are as follows: The first involves correlating

[1] Manuscript received by the Secretary of the Society September 11, 1917.
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the peneplain with an unconformity. The second makes use of deposits of known age by correlating coarse deposits believed to have come from the peneplained area in the initial stages of erosion and fine deposits and limestones with final stages. The third takes account of general principles as to rate of erosion and involves projecting the present rate back and comparing it with degree of dissection of the peneplain.

Deductions more or less obviously based on the first method of attack appear in many places in the literature of the Appalachian province, but seem to need critical examination because of an apparent lack of harmony and exactness. The Cretaceous peneplain, for example, is in many places spoken of as passing beneath Cretaceous sediments, although other statements imply that its development continued during part or all of the long Cretaceous period.

The second kind of evidence seems to have been first used extensively by Hayes and Campbell,[2] who correlate the finishing of the Cretaceous peneplain with the Selma chalk and that of the Tertiary peneplain with Oligocene limestone. A danger in using this method is that a peneplain may be correlated with the wrong limestone.

The third line of evidence, involving deductions based on the rate and amount of erosion, seems to have been little used, probably because generally regarded as extremely uncertain.

Times of Formation of Appalachian Peneplains

The quotations given below have been selected for the purpose of setting forth current views as to the age of the Appalachian peneplains, and also the basis of these views so far as can be indicated by short quotations. It will be argued later that the evidence is not sufficient to warrant the conclusions that have been drawn, and that they harmonize quite as well, if not better, with a different set of conclusions.

Apparently the earliest discussion of the ages of the Appalachian peneplains is the classic paper by Davis[3] on the rivers and valleys of Pennsylvania, in which he speaks of "Jura-Cretaceous denudation" which "ended in the production of a general lowland"; . . . and of "Tertiary base-level lowlands," thus giving the impression that both the Jurassic and Cretaceous periods were occupied in the production of an older peneplain and the Tertiary period in the development of a younger. In a later

[2] C. W. Hayes and M. R. Campbell: Geomorphology of the southern Appalachians. Nat. Geog. Mag., vol. 6, 1894, pp. 63-126, pls. 4-6.

[3] W. M. Davis: The rivers and valleys of Pennsylvania. Nat. Geog. Mag., vol. 1, 1889, pp. 197 and 199.

paper, however, he states[4] concerning the Cretaceous peneplain in New Jersey:

"The Schooley peneplain is indicated by the crest and summit altitudes of Kittatinny Mountain; . . . its seaward portion descends slowly beneath a cover of unconformable Cretaceous beds."

If so, it must immediately antedate these Cretaceous beds. It should be noted parenthetically that some physiographers[5] have come to the conclusion that the Kittatinny and Schooley peneplains are not the same. In the same year Davis[6] writes still more explicitly:

"The date of the completion of the New Jersey peneplain . . . is well defined. . . . If the gently inclined peneplain be followed from the highlands toward the southeast, . . . it is found to descend below the oldest of the Cretaceous beds. . . . The weak Triassic formation . . . had been baseleveled in Jurassic time." The highlands were then "worn down to a less and less relief, and when the whole of Cretaceous time had elapsed the highlands must have reached the even surface now so conspicuous. . . . Erosion of the surface may have continued into Tertiary time."

Hayes and Campbell[7] say that

"during Cretaceous time the condition of stability prevailed in this region for the longest period of which we have any record in its history. . . . Throughout this period of exceptional quiet erosion was in progress, reducing the surface toward baselevel. The period of Tertiary baseleveling, on the other hand, was comparatively short."

Figures 1 and 3 of their discussion show a long period of erosion and gradual reduction toward baselevel, "reaching from the final emergence (Permian?) of the western half of the province to near the close of the Cretaceous period," and a shorter cycle occupying a little more than half the time since the opening of the Tertiary, followed by a still shorter cycle extending to the present.

Keith[8] recognizes two Cretaceous, two Tertiary, and two Pleistocene "baselevels" in the region west of Washington, D. C. A portion of his summary of the history of this region is as follows:

11. Uplift, Newark deformation, and erosion to Catoctin baselevel.
12. Depression and deposition of Potomac, Magothy, and Severn.

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[4] W. M. Davis: Rivers of northern New Jersey. Nat. Geog. Mag., vol. 2, 1890, p. 86.

[5] G. W. Stose: Description of the Delaware Water Gap quadrangle, Delaware Water Gap, Pennsylvania-New Jersey. U. S. Geol. Survey, topographic sheet, April, 1916.

[6] W. M. Davis: The geologic dates of origin of certain topographic forms on the Atlantic slope of the United States. Bull. Geol. Soc. Am., vol. 2, 1890, p. 554 et seq.

[7] Nat. Geog. Mag., vol. 6, 1894, pp. 69 and 84 and figs. 1 and 3.

[8] A. Keith: Geology of the Catoctin belt. U. S. Geol. Survey, Fourteenth Ann. Rept., pt. 2, 1894, pp. 293-395.

13. Uplift southwestward and erosion to baselevel.
14. Uplift warping and degradation to Tertiary baselevel; deposition of Pamunkey and Chesapeake.
15. Depression and deposition of Lafayette.
16. Uplift and erosion to Lower Tertiary baselevel.
17. Uplift warping and erosion to Pleistocene baselevel; deposition of high level Columbia.
18. Uplift and erosion to Lower Pleistocene baselevel; deposition of low level Columbia.
19. Uplift and present erosion.

Hayes,[9] concerning the age of the Cumberland peneplain, says:

"As to the length of time which it [its development] covered there can be little question, as its limits are tolerably well fixed, the beginning being the emergence at the close of the Carboniferous and the end being the uplift near the close of the Cretaceous."

Keith,[10] however, says that "Appalachian degradation was marked by at least seven periods of approximate reduction. Each of these produced a vast series of peneplains which appear in various forms at the present day." Later work has convinced him[11] that peneplains of several other ages are present in the province.

It is worthy of note that all physiographers who have written on the subject seem to infer that parts of all peneplains formed since Carboniferous time remain to the present day, the oldest and highest remnants being parts of the first peneplain formed. Mr. Keith,[12] however, now states that he did not intend to express such an opinion in the foregoing quotation, and does not believe that parts of all peneplains have been preserved, since some of small extent may have been completely removed by later and larger ones.

From a study of the region between northern Massachusetts and the Potomac, Barrell[13] reaches the conclusion that instead of remnants of one or more peneplains the region shows eleven sea-cut terraces, two of which are as old as Cretaceous.

Chamberlain and Salisbury[14] say that "the Kittatinny baselevel was

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[9] C. W. Hayes: Physiography of the Chattanooga district in Tennessee and Alabama. U. S. Geol. Survey, Nineteenth Ann. Rept., pt. 2, 1899, p. 38.

[10] A. Keith: Some stages of Appalachian erosion. Bull. Geol. Soc. Am., vol. 7, 1895, p. 524.

[11] Oral communication.

[12] A. Keith: Oral communication.

[13] Joseph Barrell: Piedmont terraces of the northern Appalachians and their mode of origin (abstract); post-Jurassic history of the northern Appalachian (abstract, with discussions). Bull. Geol. Soc. Am., vol. 24, Dec. 23, 1913, pp. 688-696.

[14] T. C. Chamberlain and R. D. Salisbury: Geology, vol. 1, 1904, p. 159.

completed early in the Cretaceous period, and hence it is sometimes known as the Cretaceous baselevel."

Willis,[15] in his monograph on the northern Appalachians, describes the Kittatinny peneplain, but passes over its age with the statement on page 189: "Geologists date this Kittatinny plain as of the so-called Cretaceous period of the earth's history." In a later paper,[16] however, he says:

> . . . "The surface of the crystalline rocks beneath these (Mesozoic) sediments . . . is a plain sloping beneath the sediments toward the Atlantic, rising from under the sediments westward toward the Appalachian Mountains. . . . By filling the valleys in such a manner as to connect all ridges whose crests fall into the general slope, there is restored the plain, which was eroded nearly to sealevel during the Cretaceous period.
>
> "That old plain, now elevated and dissected, has been traced over New England, over the Middle States, and over the South Atlantic States. It coincides with the summits of the highest ridges, which in Maryland are represented by the Catoctin, the Blue Ridge, the Alleghany ridges, and the Cumberland plateau. Only in North Carolina and the interior of New England are surviving mountain summits of that date.
>
> "Recognition of the old Cretaceous plain, surviving in the ridge summits of the present time, is the first step in reading the Cenozoic history of Appalachia."

It will be noted that Willis, like others, speaks of the plain as passing under Cretaceous deposits and yet as having been formed during Cretaceous time.

The Appalachian folios of the Geologic Atlas of the United States treat the subject of peneplains in various degrees of detail. For example, Hayes'[17] discussion of peneplains in the Columbia, Tennessee, folio seems surprisingly brief. It is found under the heading topography, the chapter on history treating only the sedimentary record. It is stated that "the elevation of the region to its present altitude (after the formation of the Highland Rim peneplain) was not continuous, but occurred at several periods separated by intervals of repose." It is interesting to note from this quotation that Hayes recognized more than one erosion stage after the formation of the Highland Rim peneplain, this position seeming to accord more closely with Keith's idea of multiple peneplains, expressed in 1895, than with his own of two peneplains, expressed in the same year.

In most of his folios Keith speaks of peneplains which evidently are not equivalent to the two described by Hayes and Campbell, or the three

[15] Bailey Willis: Nat. Geog. Soc. monographs, vol. 1, 1896, pp. 169-202.

[16] Bailey Willis: Paleozoic Appalachia, or the history of Maryland during Paleozoic times. Geol. Survey Special Pub., vol. iv, pt. 1, 1902, pp. 91 and 92.

[17] C. W. Hayes and E. O. Ulrich: U. S. Geol. Survey Geol. Atlas, Columbia Folio, No. 95, 1903, p. 1.

described by Hayes, or even the several later referred to by Hayes. For example, in the Roan Mountain folio he speaks of four peneplains which are represented in the one quadrangle, although he does not state their age.

Although some folios refer to the age of the peneplains in general terms only, some are more specific. For example, in a late folio Campbell, Clapp, and Butts[18] say:

"Evidence of at least one cycle of erosion and of subsequent uplift in the Mesozoic era is preserved in the Appalachian province.

"The old peneplain can be traced eastward and southward, and in New Jersey and Alabama passes beneath deposits of early Cretaceous age. This fact proves that the peneplain was completed and submerged around its margins previous to early Cretaceous time."

Thus, according to what treatise one chances to pick up, he may infer, with more or less uncertainty, that the Cretaceous peneplain was completed some time before the opening of the Cretaceous period and was remodeled by the advancing Lower or Upper Cretaceous sea, or that it was completed at one time or another in this long period, or even in the early part of the following Tertiary. Many writers are not explicit and precise; some, perhaps, because they believe the information insufficient to warrant exact dating of the surface. In any case the most prevalent impressions seem to be that the Cretaceous, Kittatinny, Schooley, and Cumberland peneplains are approximately equivalent in age and slope down below the Cretaceous system of deposits, and that the Tertiary, Summerville, Highland Rim, and Shenandoah are equivalent and their development occupied the latter part of Cretaceous and the early part of Tertiary time.

The statements regarding the ages of the Appalachian peneplains, though somewhat indefinite, seem to have been accepted almost without question or critical examination. They are repeated in a multitude of publications and are used as perfectly good foundation material for other inferences.

Peneplains many hundred miles away, and far beyond the limits of continuous tracing, have been correlated with the Appalachian peneplains. In northwestern Illinois, Hershey[19] and Bain[20] describe peneplains of Tertiary and probable Cretaceous age.

[18] M. R. Campbell, F. G. Clapp, and Charles Butts: U. S. Geol. Survey Geol. Atlas, Barnesboro-Patton Folio, No. 189, 1913, p. 9.

[19] O. H. Hershey: Pre-Glacial erosion cycles in northwestern Illinois. Am. Geol., vol. 18, 1896, p. 72. The physiographic development of the upper Mississippi Valley. Am. Geol., vol. 20, 1897, pp. 246-268.

[20] H. F. Bain: Zinc and lead deposits of the upper Mississippi Valley. U. S. Geol. Survey Bulletin 294, 1906, pp. 15 and 16.

Some have gone so far as to work the rule the other way, and instead of dating a peneplain by deposits of known age date a deposit by a peneplain on which it is believed to rest. Fuller and Clapp,[21] for example, map and describe a formation as Eocene because they believe that the Tertiary peneplain was completed at about that time and that the deposit was laid down on the old plain.

The general implicit faith in the statements as to the age of the Appalachian peneplain is further exemplified by the dating of peneplains thousands of miles away by comparison with the Appalachian peneplains of supposedly known age. In his Forty-ninth Parallel report Daly[22] says:

"The evidences against the hypothesis of a mid-Tertiary peneplain on the Front ranges seem to be powerful. First, the time allowed is not sufficient for peneplanation or even past-mature development, followed by uplift and mature dissection in a second cycle. All post-Cretaceous time has not been enough to destroy the large monadnocks on the well established Cretaceous peneplain of the Appalachians, though their rocks are not sensibly stronger than those of the Front ranges of the Cordillera."

Evidence as to Age of Peneplains

GENERAL STATEMENT

The best evidence as to the age of the Appalachian peneplains seems to the writer to lie in the results of correlation with unconformities and deposits in the Coastal Plain and in knowledge concerning the rate and amount of erosion. The correlation rests on continuous tracing of peneplains and coincidence of their projected planes and on the principle that deposits laid down near the close of an erosion cycle are more scant and finer in grain than those connected with an earlier part. The data as to rate and amount of erosion consist of (1) the present rate under various conditions and an estimate of the length of certain periods of geologic time, (2) the amount of material which has certainly been removed from some areas, and (3) the quantity of the deposits which have been derived from the province in various periods and epochs.

CORRELATION WITH BURIED PENEPLAINS

Statements concerning the local altitude and slope of peneplains in various parts of the Appalachian province are much more abundant than those concerning the supposed buried correlatives. It is often remarked concerning a peneplain being described that it has such and such alti-

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[21] M. L. Fuller and F. G. Clapp: U. S. Geol. Survey, Patoka Folio, No. 105.

[22] R. A. Daly: North American Cordillera at the Forty-ninth Parallel, pt. ii, Memoir No. 38, Canada Department of Mines, 1912, p. 608.

tudes, and that, sloping seaward, it passes beneath deposits of a certain age, but it is rare that the slope of the buried surface for even a short distance is set forth.

However, from published and unpublished observations together, the general lay of the buried peneplains can be ascertained fairly satisfactorily. One in particular—the floor under the Cretaceous formations—can be determined with considerable accuracy. The facts come from (1) outcrops in a belt along the landward side of the Coastal Plain, (2) well records in this belt, and (3) well records in the middle and seaward portions. They show that to the east, south, and west this surface slopes away from the Appalachians at a rate generally about 30 feet to the mile. In places the slope is steeper. In the District of Columbia it is fully 100 feet to the mile. In a few places, as in North Carolina, where there has been uplift near the present coast, it is more gentle. But such departures are not enormous and are found in only a few places. The slope as a whole seems remarkably uniform.

On the other hand, according to all descriptions and maps, the slopes of all peneplains about the adjoining margin of the Appalachian province is much less, ranging from 5 to 15 feet to the mile. This is especially noteworthy and reliable in the south, where there has been little deformation. Therefore, testimony based on projected planes indicates that the floor under the Cretaceous deposits is older than the so-called Cretaceous peneplain; older even than the monadnock tops supposed to rise above the surface. Even the unconformity at the top of the Cretaceous seems to have a steeper slope than the adjoining portion of the so-called Cretaceous peneplain.

If it be argued that a gradual increase in slope toward the sea is to be expected, it may be replied that according to descriptions and general altitude data the slope of exposed peneplains in a broad belt adjoining the Coastal Plain decreases seaward, and the belt of greatest slope is many miles landward from the Coastal Plain border. Probably all will agree that cross and longitudinal profiles of Appalachian peneplains would show, as a general rule, a nearly horizontal central portion from which the slope increases in all directions outward for some scores of miles, beyond which the inclination decreases as the altitude approaches sealevel, the central mountainous portion having suffered much the greatest uplift. Indeed, there is a generally accepted inference that in the upper portion of the Mississippi basin two or more of the peneplains, each approaching sealevel (or local baselevels not far above sealevel) at a declining rate, become so nearly coincident that they can not be distinguished.

Downwarping due to isostatic adjustments can scarcely save the good

standing of the inferences concerning the ages of the peneplains, for in the first place it would simply destroy the principal line of evidence as to their age, and in the second it could scarcely account for an abrupt down-bend along the original margin of the Cretaceous and Tertiary deposits, and surely not along what happens to be their present margin, for this is continually shifting seaward. It may be argued that since remnants of the so-called Cretaceous peneplain are scarce in a belt bordering the Coastal Plain, it may have been uplifted in this belt, so as to give it a greater slope on the seaward portion of the belt and make it harmonize with the peneplain under the Cretaceous deposits. This also would set aside the line of evidence generally regarded as most valuable, namely, that concerning coincidence of projected planes. If the possibility is real, then we must at least abandon such inferences as that the Cumberland and sub-Cretaceous peneplains are the same, for any other correlation would be as reasonable. On the other hand, since, with the possible exception of the Nashville dome, which has been slightly uplifted, and a district just west of Washington, D. C., there is little indication of differential uplift in the Piedmont province and other portions of the bordering belt; the general discordance in positions and slopes of plains that have been correlated requires presumably some other explanation.

The following table shows the general form and extent of the Coastal Plain deposits:

EXTENT OF ATLANTIC COASTAL PLAIN DEPOSITS

Place through which section is taken.	Approximate altitude at inner border.	Distance from inner border to—			Thickness of deposits at present coast.
		Present coast.	300-foot 50-fath.) contour.	2400-foot (400-fath.) contour.	
	Feet	*Miles*	*Miles*	*Miles*	*Feet*
Southern New Jersey....	200	60	130	140	2,000±
District of Columbia.....	400	120	160	175	2,500?
Norfolk, Va..............	250	90	155	160	2,500±
Wilmington, N. C........	275	115	175	205	1,600±
Charleston, S. C.........	425	125	170	255	2,500±
Savannah, Ga............	400	125	195	240	2,500? [23]
Montgomery, Ala., and Pensacola, Fla.........	550	165	200	250	4,000? [23]
Approximate (average)...	400	115	170	200	2,500

The figures in the above table are believed to represent correctly the general cross-section form of the land portion of Coastal Plain deposits

[23] According to T. W. Vaughan and L. W. Stephenson, perhaps somewhat too low (oral communication).

and to give some indication of the form and seaward extent of the submerged portion. They are based on a large number of observations made along the outcrops of the various beds and in the drilling of wells. They show a generally uniform seaward slope of the floor under the Cretaceous of 25 to 30 feet to the mile. Data on the slope of the base of the Tertiary are not so abundant, but apparently this slope is more like that at the base of the Cretaceous than like the present surface, the average general seaward slope of which is less than four feet to the mile.

The extent of the submerged portion of the Coastal Plain deposits can only be conjectured, still from a study of the fairly definite information concerning the land portion, the shape of the continental shelf, and the known Cretaceous and Cenozoic history of the Atlantic coast some inferences can be drawn which carry a rather heavy weight of probability. On such a basis, involving seaward extrapolation of the base of the deposits, the following table has been compiled:

Average Cross-section Area of Atlantic Coastal Plain Deposits

Land portion	760 million square feet (estimated)
Between coast and 50-fathom contour.	840 million square feet (conjectural)
Between 50-fathom and 400-fathom contours	400 million square feet (conjectural)
Between 400-fathom and 1,500-fathom contours	200 million square feet (conjectural)
Total........................	2,200 million square feet (conjectural)

Even in the Gulf embayment, where the deposits extend much farther inland and the base slopes not toward the sea, but more nearly toward the axis of the embayment, the rate of decline is still the same, being generally from 27 to 30 feet to the mile. A dip section along a curving line from the northeast corner of Mississippi southwest and south would show the altitude of the inner border of the Coastal Plain about 850 feet, the distance to the present coast 440 miles, to the —300-foot contour 500 miles, and the —2,400-foot contour 530 miles, figures more than twice as great as those for corresponding features given in the above table. But the slope of the peneplain on which the Coastal Plain sediments rest is certainly about 30 feet to the mile for 100 or 200 miles, and several deep wells recently drilled near Vicksburg and Jackson, together with other wells in Louisiana that although thousands of feet deep do not reach strata within thousands of feet of the base of the Cretaceous, indicate that this slope continues nearly, if not quite, to the Gulf. The Coastal Plain deposits at Vicksburg are probably 4,000 to 4,500 feet thick and at the

coast southwest of New Orleans between 11,000 and 15,000 feet, the base being far lower than the continental shelf and one-half to three-fourths as low as the bottom of the Gulf.

NATURE OF DERIVED DEPOSITS

The use of fineness of grain and chemical deposits in dating peneplains seems rather unsafe, because it so generally depends on which peneplain and which limestone are to be correlated, and there seems to be much difference of opinion as to the length of erosion cycles. Does the development of a peneplain generally require periods or epochs, or less than an epoch, or is it quite impossible to estimate? If it were known that about a period is required, that there are in the Appalachian province but two or three peneplains, and in the deposits two or three main limestones separated by many formations, the presumable implication would be clear.

AMOUNT AND RATE OF EROSION

If 30 million years have elapsed since Paleozoic time and the rate of erosion of the province has been the same as the present average rate for the United States, an average of over 3,000 feet of rock would have been removed, and it would seem very unlikely that any portion of a surface formed in pre-Cretaceous time could have survived this general degradation. To be sure, this figure may be far from correct, but it seems doubtful if it is many fold too large. So surely as rain has fallen on the earth, every square mile of the land area has annually lost through solution alone a great many tons. Furthermore, the streams of lowlands, commonly at least, carry much sediment; so that, whether high or low, no part of the Appalachian province except those areas where deposits have been formed can have escaped continual reduction.

If the Cretaceous and Cenozoic deposits of the Coastal Plain were to be spread evenly over the area outside the Coastal Plain now draining to the Atlantic and eastern Gulf, they would apparently make a layer about 3,200 feet thick, and probably the reduction that they represent is considerably more, one reason being that much of the lime, etcetera, of the eroded area has been carried far away. True, the Coastal Plain border has been shifting seaward; the eastern border of the Mississippi basin has migrated more or less, and some of the Coastal Plain sediments may have been brought along shore from other regions; but after allowances are made, it seems probable that the quantity of Coastal Plain sediments indicate a removal from the Appalachian region of an average thickness between 2,000 and 5,000 feet. If the amount were only 1,000 feet, it would still be sufficient for the present argument.

In areas of intense deformation a total reduction of 10,000 to 30,000 feet can be demonstrated, yet these are the areas in which surfaces older than the so-called Cretaceous peneplain are said to be preserved.

If the central part of the province has been reduced from 3,000 to 30,000 feet, it seems improbable that any portion of the present surface is even as old as early Tertiary and doubtful if any is a fourth or even a tenth as old as Jurassic or pre-Cretaceous.

Summary

Although the published statements concerning the ages of the Appalachian peneplains are inharmonious and many lack clearness, precision, and supporting evidence, they seem to be accepted with implicit confidence. In particular the conclusion that parts of all peneplains developed since Paleozoic time have endured to the present, and that some of these are early Cretaceous or older seems to be unquestioned; yet data which have been generally available indicate that all peneplains of which remnants exist today are younger than the floor under the Cretaceous with which one or more have so frequently been correlated, and additional data along several lines gathered during the past ten years support this inference.

It is the writer's opinion that no portion of any surface so old as early or even late Mesozoic can have endured exposure to the elements in the Appalachian province until the present day, and that the oldest peneplain of which remnants exist was finished in Tertiary time. It seems to him probable that no portion of a surface even so old as Middle Tertiary has been preserved intact without perceptible reduction and remodeling. But however this may be, the evidence as to the ages of the peneplains seems to be fairly harmonious and to indicate ages more recent than those heretofore assigned.

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OOLITES IN SHALE AND THEIR ORIGIN[1]

BY W. A. TARR

(Read before the Society December 29, 1917)

CONTENTS

GEOLOGY OF THE OOLITIC SHALE

Oolites are most commonly found in limestones, dolomites, or iron ores. Their occurrence in shale has not been recorded, as far as the writer is aware. The oolites described in this paper are found in a shale member of the red beds of the Wind River Mountains near Lander, Wyoming.

These red beds of Wyoming owe their name to their prevailing color. They consist of a series of shales, sandstones, thin beds of limestone and dolomite, and some lenticular beds of gypsum. The various beds show all degrees of gradation into one another, the majority being somewhat calcareous. The shales are often sandy and the sandstone may contain some argillaceous material. The limestone and dolomite beds are, however, quite pure. As this formation is very poor in fossils, its age is still a matter of conjecture. Paleontologic work by Williston[2] and Branson[3]

[1] Manuscript received by the Secretary of the Society December 29, 1917.
[2] S. W. Williston: Jour. Geol., vol. 12, 1904, p. 688.
[3] E. B. Branson: Manuscript.

show that the upper portion at least is Triassic. Their conclusions are based on reptilian and amphibian remains found in a member of this upper portion. Williston has given the name Popo Agie to this fossil-bearing member.[4]

It is this fossiliferous member that is discussed in this paper, as it is oolitic, in considerable part at least. Branson has described these beds,[5] and although the writer has studied them in the field, the following notes regarding them are based on Branson's description, as he has studied them along the entire front of the Wind River Range.

The thickness of the beds vary, ranging from less than 20 to more than 60 feet. In the main, this member is a sandy shale. The upper bed is

FIGURE 1.—*Nodular Structure of oolitic Shale after Weathering*

massive, ranging up to 15 feet in thickness, and "consists of nodules of purplish, argillaceous sandstone." Branson suggests that the massive character of this bed may be due to the destruction of the bedding planes through the exposure of the beds and the alternate development and filling of sun-cracks, as described by Barrell.[6] The color of the Popo Agie beds shows a remarkable variation, ranging through shades of green, red, brown, yellow, purple, and tan, "with occasionally white beds and now and then carbonaceous bands. Not infrequently included fossil bones are black, owing to carbonization." The beds are fine-grained throughout, and much of the formation is decidedly oolitic. The amount of the

[4] Ibid.

[5] E. B. Branson: Origin of the Red Beds in western Wyoming. Bull. Geol. Soc. Am., vol. 26, 1915, pp. 217-230.

[6] Joseph Barrell: Bull. Geol. Soc. Am., vol. 23, 1912, p. 426.

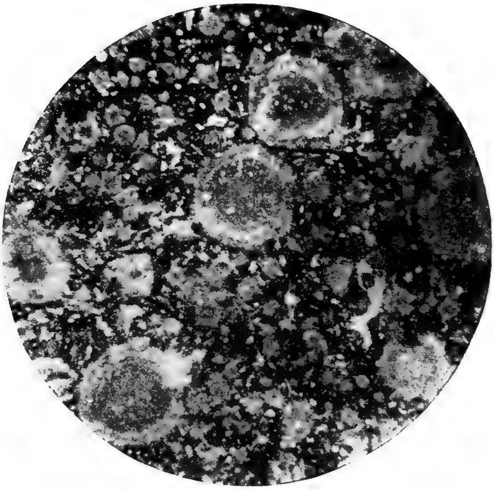
FIGURE 1.—LARGE AND SMALL OOLITES AND THE DISSEMINATED SAND GRAINS. (× 25)


FIGURE 2.—DISTRIBUTION OF THE SAND GRAINS AND THE ZONES IN THE OOLITES. (× 41)

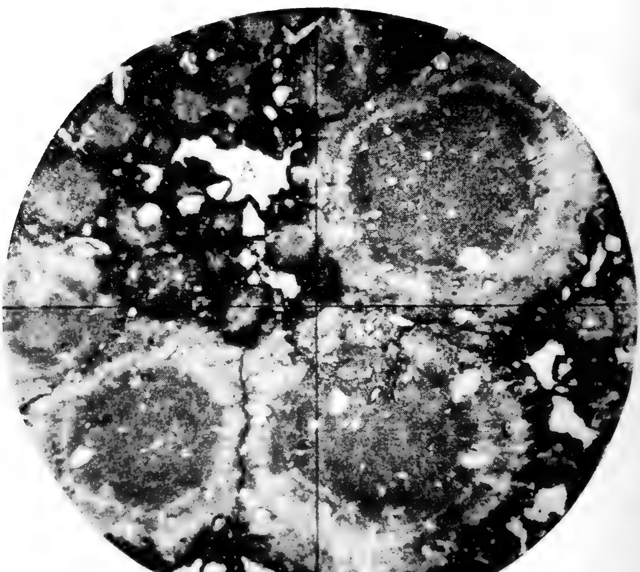
FIGURE 3.—IRREGULAR DISTRIBUTION OF THE SAND GRAINS IN BOTH SHALE AND OOLITES

A is a hole in the slide. (× 87)

OOLITES IN THE RED SHALE

oolites varies in the different colored phases, but they are uniformly distributed within each phase.

The structural features of the beds are interesting. Evidences of cross-bedding are rare, and "here and there a conglomerate, varying in composition from pebbles of various kinds of rocks to pieces of bone and teeth of reptiles and amphibians, occurs among the other rocks." All the beds show rapid lateral variation in composition, as well as in color, and a given bed may change in this way within a few feet. Nodules of calcite which are 8 to 10 inches in diameter occur locally. A remarkable feature of the beds is the nodular form the material assumes on weathering. Many of these nodules are 12 to 14 inches in diameter and most of them are well rounded (figure 1). In the upper massive layer this nodular structure is especially well developed.

Description of the Oolites

GENERAL STATEMENT

The material which the writer collected for study represents principally the red, yellow, and green phases of the formation. Oolites occur in other colored shales, but the above are taken as being typical of the oolitic phases. Whatever the color of the rock, the oolites are white. Only one exception to this was observed, the interior of an oolite being pink and the remainder white.

THE OOLITES IN THE RED SHALE

This shale is a dark purplish red in color, and the oolites in it comprise more than 50 per cent of the rock. The shale is sandy. The grains are very small and not readily recognizable, although they may be seen through a binocular with a magnification of twenty-five. The oolites show a tendency to aggregate into groups of from 6 to 25 in number. They are rarely near enough to touch one another in these aggregates, but are merely more numerous there than elsewhere (figure 2). They are not related in position to any structural features of the rock.

Under the microscope the sand is seen to be uniformly disseminated throughout the shale and the oolites (plate 21, figures 1-3). It consists of angular quartz grains, which are rarely over .1 millimeter in diameter, the majority being less than .05 millimeter.

The oolites occur in two distinct sizes. The larger ones average about .65 millimeter in diameter, ranging from .5 to .7 millimeter. This constant uniform size of about .65 millimeter should be noted. The smaller

oolites are rarely larger than .26 millimeter and range from .1 to .13 millimeter. Those of the larger size comprise about 17 per cent of the slide and the smaller ones probably twice this amount.

The larger oolites are concentrically banded (plate 21, figures 1 and 3), and this feature is occasionally seen in the smaller ones. There is no

FIGURE 2.—*Distribution of the Oolites in red Phase of the Shale*

Slightly enlarged

variation in their color, as the rings are due to the variations in the diaphaneity of the material. The interior is more opaque than the outer zone, due, in part, to included clay. When several rings occur they are always in the outer portion of the oolite (plate 21, figures 2 and 3). The outer edge is not smooth, but irregular. Measurements of the central

FIGURE 1.—LARGE AND SMALL OOLITES. (× 25)

FIGURE 2.—FOUR NARROW ZONES IN THE OUTER PORTION OF THE LARGE OOLITES. (× 87)

OOLITES IN THE YELLOW SHALE

opaque zone indicate that all these inner zones are of the same size. Likewise, the outer spheres are of equal size in all the oolites. These facts point to uniform conditions during the periods of growth of the oolites.

The oolites are composed of silica and are without a visible nucleus, unless the assumption is made that the smaller oolites acted as nuclei. This may have occurred in some of the oolites. They have a faintly granular appearance under the higher power of the microscope. Grains of sand preserve their uniform spacing in the oolites as in the shale, and may occur anywhere in the oolite (plate 21, figure 3). There is no evidence that they were pushed aside during the growth of the oolite, and their position indicates that they have not acted as its nucleus. This is of interest, for most oolites are usually described as having a nucleus. This, however, is not essential, as oolites may develop without a nucleus. No cross is produced under crossed nicols, which is usually the case when the material is chalcedony, as these oolites appear to be. Two oolites may occur so close together that they have interfered with each other's growth on the sides in contact, but there is little or no distortion of the concentric zones as a result, and the line of contact is a straight line (plate 21, figure 2).

OOLITES IN THE YELLOW SHALE

The yellow shale is distinctly less sandy than either the red or the green shale. The spacing of the oolites in this rock is like that in the red shale (plate 22, figure 1). Under the microscope the ground-mass is seen to be opaque yellow clay, and occasionally there are a few grains of calcite.

The oolites are of two sizes, as in the red shale. The larger ones average about .62 millimeter in diameter and the smaller about .156 millimeter, ranging from .130 millimeter to .260 millimeter. The larger oolites comprise about 14 per cent of the slide and the smaller more than 50 per cent. It should be noted that the large oolites are of approximately the same size as are those in the red shale (see plate 21, figure 1, and plate 22, figure 1).

The oolites, especially the large ones, are concentrically banded, the concentric rings being due to variations in the diaphaneity of the material. There is usually an opaque central sphere in the large oolites which is of nearly the same diameter, .09 millimeter, in all. This opaque zone, with its uniform diameter, occurs in the small oolites also when their diameter exceeds that of the opaque zone. The next prominent concentric sphere is .368 millimeter in diameter and occurs in all the large oolites, whether or not the above noted central opaque zone is present. Immediately outside of this sphere are four concentric spheres having a total width of

.078 millimeter (plate 22, figure 2), and the next is the outermost sphere, which is quite translucent. There is a suggestion of a radial structure in some of the oolites, but it disappears entirely under crossed nicols.

All the large oolites and many of the small ones show a slight flattening, so that they have a somewhat elliptical form. The concentric spheres are slightly broken at the sides. In all the oolites the borders are not distinct and sharply cut, but are more or less irregular.

There is no evidence of a nucleus in any of the oolites, and the surrounding material is not disturbed in any way, showing that all growth of the oolites had ceased before the consolidation of the material. A striking feature of the rock is the development, on a microscopic scale, of the structural feature called stylolites. Their description will be included in a forthcoming paper on stylolites.

THE OOLITES IN THE GREEN SHALE

The green shale is sandy, like the red shale, and contains more oolites than either of the others, especially more of the large oolites. They show the same tendency to aggregation, but are in no way related to bedding planes or other structural features of the rock.

The microscope shows that the oolites contain less sand than those in either of the other shales. It is scattered throughout the rock as in the other shales, and when an oolite contains one or more grains they are in no way related to the oolitic structure, but occur in any portion of it, the oolite having simply inclosed them.

The diameter of the oolites averages slightly over .6 millimeter, while occasionally there is one which has a diameter of nearly a millimeter. The small oolites are about the same size as those in the other shales. The numerous concentric rings of the oolites in the red and yellow shales are missing in those of the green shale. There is one narrow, translucent ring which is practically the same size in all the oolites—that is, .266 millimeter in diameter. This uniformity in diameter was noted in the oolites of the other shales. This would hardly be expected, for the materials came from different portions of the formation, and, as already noted, a characteristic feature of the beds is the abrupt variation in composition. The larger oolites and the smaller ones appear to be of about the same average size in all the shales.

Numerous grains of calcite occur in the green shale and sometimes lie partly within the oolites. These grains are very irregular in shape and may occur in any portion of the shale. This distribution indicates that the grains of calcite are not unchanged portions left by a replacement of calcite by silica, but that the calcite grains, like the sand grains, were

deposited at the same time as the oolites and other materials of the shale.

A megascopic study of a piece of the material different from those described above shows many small, irregular pieces of impure calcite or rather calcareous shale. This material contains also small nodules of limonite, some nodules being one-half inch in diameter. The oolites are disseminated through the sandy shale which surrounds this calcareous, limonitic material. All the different materials occurring in these shales show by their relationship that they were deposited simultaneously. Some of the shales contain numerous grains of what appears to be glauconite. It is possible that the green shale may owe its color, in part at least, to this mineral. The color of the red and yellow phases is due to iron oxides.

SUMMARY

The oolites are found scattered throughout the shale, which may or may not be sandy. They are of two sizes, the larger averaging about .6 millimeter and the smaller about .15 millimeter in diameter. They are composed of silica and are made up of concentric spheres. These concentric spheres have approximately the same diameter in each sort of shale, but not the same in the various sorts. None of the oolites have a nucleus, although some of them contain considerable clay in the inner sphere. As a rule, they are without a radial or tangential arrangement. There is a faint radial arrangement in the oolites of the yellow shale, but they do not show a cross between crossed nicols. Sand grains are scattered throughout the shale and the oolites, but are in no way related to the growth of the oolites. Irregular grains of calcite occur in the green shale and in the oolites in it, but are not related to the oolites. The relationship of the oolites to each other and to the surrounding material indicates that their growth was attained before the beds were consolidated.

Origin

INTRODUCTION

The writer believes that the oolites were always siliceous as they are now. While this conception of the origin may appear unusual, yet the evidence is such as to strongly support the view. As will be shown later, much silica is being added to the waters of the sea by all streams. This silica must be deposited because it is not now a constituent of the sea-water in appreciable amounts, so it should not be regarded as so very unlikely that some of it may have assumed the spherical form of oolites in the rocks. Such forms are typical of all amorphous substances, and

gels are especially apt to assume such shapes because of the lack of any cohesive force save surface tension. Surface tension serves a very important part in the development of the oolites, as it tends to aggregate the gel into small spherical bodies. It is this combination of much silica being added to the seas, its precipitation as a gel, and the tendency of gels to assume spherical forms that strongly favor the view that the siliceous oolites are original.

EVIDENCE FOR THE THEORY OF PRIMARY DEPOSITION

The following reasons are the most important for believing that the silica was deposited at the same time as the inclosing rock, which was a sandy shale in this case:

1. The uniform distribution of the oolites through the shale without any evidence of accumulation along a given plane is in favor of this view. The shale itself may or may not be entirely without banding. Uniform distribution is what would be expected if the siliceous material accumulated along with the muds of the shale, both settling to the bottom as they were added to the water.

2. The uniform distribution of sand grains in both oolites and shale favors the primary deposition theory. The sand grains were carried down by the muds and were included in the gel of the siliceous oolites. Their arrangement in the oolites shows that they were simply included in the soft material and were in no way affected by further enlargement of the oolites—a fact wholly compatible with the growth of gels. Possibly some of the sand grains were acquired by adhering to the gel. There is also considerable kaolin scattered through the oolites, especially in the central zone of some of them. This is evidently due to the central zone forming soon after entering the water, where it was, of course, very muddy.

3. All growth of the oolites ceased as soon as they were buried in the muds. They could grow as long as they were settling through the water and until they had been buried by the accumulation of mud on the bottom. Practically all the silica went into the oolites, for the shale is only slightly plastic.

4. The interference of the oolites is a very suggestive feature. As can be seen in the plates, the oolites are frequently in contact, the line of contact usually being regular. There is no evidence in any of the shales that the inner zones have been deformed by their growth. The oolites have evidently continued to grow after coming to rest on the bottom. Two adjacent oolites grew uniformly and thus preserved a regular line of contact. If a small oolite was in contact with a large one it was usually partly surrounded by the larger.

This interference is characteristic of this type of oolites. A large number of slides of calcareous oolites from all parts of the United States were examined, and in not a single instance had the oolites interfered with each other's growth. They were always merely in contact. This is significant as showing that the oolites were growing in the muddy water, and that their growth was not due to material acquired by rolling about on the bottom.

5. There is a slight flattening of the oolites in the yellow shale, but it is not noticeable in the other phases. This flattening was produced during the consolidation of the shales, but after growth of the oolites had ceased.

6. The growth of the oolites was stopped by the accumulation of sufficient mud above the oolites to prevent any more silica reaching them. This was evidently the factor which produced the uniform size of the oolites, and it points to a uniform rate of deposition.

7. The beds which contain the fossils were deposited in shallow water and were probably loose, soft, sandy muds. Branson[7] has cited the evidence and come to the conclusion that the red beds are, in the main, of marine origin, but that the Popo Agie beds show several evidences of subaerial origin and were formed as marginal deposits, partially marine and partially subaerial.

The writer believes that the Popo Agie beds were practically continuously under water, but that it was very shallow water and comparatively near the shore.

These points, in connection with the points made in regard to the silica, are believed to be favorable to the view that these siliceous oolites were deposited at the same time as the inclosing shale.

EVIDENCE AGAINST THE REPLACEMENT THEORY

Since the prevalent view is that all siliceous oolites are due to the replacement of calcareous oolites by silica, it will be of value to note the evidence against this view in this case. The following reasons are believed to be against it:

1. The oolites occur in shale. The writer has found no record of either siliceous or calcareous oolites occurring in shale. Under the above precipitation theory the occurrence of oolites in shale would not be unlikely, however. Leith and Mead[8] have suggested that "a large part of the silica carried in solution by rivers is deposited with the muds and clays" (page

[7] E. B. Branson: Origin of the Red Beds in western Wyoming. Bull. Geol. Soc. Am., vol. 26, 1915, pp. 217-230.

[8] C. K. Leith and W. J. Mead: Metamorphic geology, 1916, pp. 81, 102-104.

81), and that "colloidal silicic acid is believed to be deposited largely with the clays and muds, as the same processes of flocculation which precipitate the colloids also throw down the finely divided sediments" (page 102). The plasticity of shales is due to colloids and the principal colloid in them is silica; so the view that the silica might assume the oolitic form at times is quite probable. That oolites are not more common in shales is due to the lack of favorable conditions for the rapid precipitation of the colloids and a lack of an abundance of colloidal silica.

2. There are no residual grains of calcite or aragonite present in the oolites. Even though aragonite is the form in which most calcium carbonate is precipitated, it is soon converted into calcite and would appear as such in the shales. A few grains of calcite, very irregular in shape, are found in the yellow and green shales. Some of these grains are in the oolites, but the majority are in the shale around them. Their form, distribution, and relationship to the surrounding material is such that to assume that the grains in the oolites are residual is to assume that the grains in the shale are also residual, and that the calcite has been replaced by shale, an assumption no one would agree to. The calcite is original, as are all the constituents of the shale. The writer has a large collection of slides of calcareous and siliceous oolites from previously described and new localities. Some of them show replacement by silica; some are wholly calcareous, and none of the siliceous oolites in shale show the characteristics of those siliceous oolites which have replaced calcite.

3. All silicified calcareous oolites show siliceous cementation. This is never present in the oolitic shale.

4. The imperviousness of clays and shales preclude any possibility of the introduction of silica into the shales. All men recognize shales as being impervious barriers to the passage of water in controlling artesian water supplies, in ore deposits, in oil fields, and also to the passage of gas in gas fields. The following extract from Leith and Mead testifies further to the imperviousness of shales:

> "Argillaceous sediments, although very porous, are characteristically impervious and do not permit even moderately free circulation of solutions. Water circulation depends on size and continuity of openings rather than on total volume of openings or degree of porosity. Cementation by infiltration of materials from extraneous sources is believed to be largely inhibited by the imperviousness of clay to free water circulation. Induration is probably accomplished mainly by compression and internal rearrangement of original constituents" (ibid., p. 103).

5. There is no adequate source of the silica with which to produce replacement. If it can not come from the outside, then only the minerals

in the shale can be a source. Very evidently it is not the quartz, for the quartz grains in the shale are sharply angular, showing no evidence of solution. The only other constituent is kaolin, and it is unlikely that any solutions in the shale would attack this extremely resistant mineral. No other silicates could be recognized in the shale. There is no more likely source from the outside, as the adjacent beds also are sandstones and shales. Suitable solvents for silica are extremely rare among ground waters, yet one must be sought if the oolites originated by replacement. The view that organic acids are adequate solvents has fallen into disfavor in recent years.

The conclusion is reached that siliceous oolites in shale do not owe their origin to the replacement of calcareous oolites.

Source of the Silica

It is believed that the oolites are due to the precipitation of colloidal silica, which was brought by the streams into the sea or inclosed body of water. The streams which flowed into this body of water drained from an unknown area to the west. The character of the rocks of this drainage area is, of course, unknown, but some part of the material in solution, at least, may have been derived from any exposed Lower Paleozoic formations. Possibly the larger portion of the drainage area consisted of Pre-cambrian and igneous rocks. It would appear that the character of these stream waters would be comparable to those of the streams that are draining areas of mixed types of rocks today. Many analyses of the waters of such streams are available, and these afford data to test the adequacy of the idea that the streams may be a source of silica.

There is only one analysis of the water of the streams in this region, and that is of the waters of the Popo Agie, which drains mainly a granitic area, but crosses Paleozoic sediments in its lower course. Slosson's[9] analysis shows that approximately 8 per cent of the material in solution is silica. Headden[10] gives an analysis of the Arkansas River at Cañon City, Colorado, which shows 8.19 per cent silica, while another stream, the Poudre River, in northern Colorado, after flowing for fifty miles over granitic rocks, contains 23.5 per cent silica. It will be necessary for our purpose to give only some averages of a number of streams in various parts of the United States. Dole[11] gives analyses of the principal streams of

[9] E. E. Slosson: Bull. Wyoming Agri. Exp. Sta., No. 24, 1895, p. 119.

[10] W. P. Headden: Bull. Colorado Agri. Exp. Sta., No. 82, 1903.

[11] R. B. Dole: The quality of surface waters in the United States. Water Supply Paper No. 236.

the eastern United States, and the following averages were made from his paper:

	Percentage of silica
Streams draining sedimentary and glacial areas	7.8
Streams draining Precambrian, sedimentary, and metamorphic rocks	21.2
Streams draining Precambrian and igneous areas	28.5

The climatic conditions for these stream areas are those of the United States east of the one hundredth meridian, so they vary widely.

Data for the streams of the Pacific coast are given by Van Winkle.[12]

The average silica content for California streams is as follows:

	Percentage of silica
Granitic areas	14.3
Igneous rocks of all kinds	17.6
Igneous and sedimentary areas	8.0
All sedimentary rocks	6.7
Average for California streams	14.3

The following figures are of interest in showing the lack of climatic influence on the amount of silica in solution:

	Percentage of silica
Average of all streams with rainfall over 15 inches	14.4
Average of all streams with rainfall under 15 inches	14.2

The majority of the Oregon streams drain areas of igneous rocks or of igneous, metamorphic, and sedimentary rocks.

	Percentage of silica
Average of igneous rocks	30.5
Average of igneous, metamorphic, and sedimentary rocks	22.6
Average of all Oregon streams	26.82

These streams are all high in silica.

Washington streams show the following silica content:

	Percentage of silica
Areas of igneous rocks	30.2
Areas of igneous and metamorphic rocks	27.1
Areas of igneous, metamorphic, and sedimentary rocks	14.8
Average of all streams, including some from wholly sedimentary areas	21.1

The above figures show that the silica content of stream waters varies considerably, but that streams which flow over igneous and metamorphic rocks are usually high in silica. It is to be noted that in most cases the total amount of dissolved solids is low in streams which contain the most

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[12] Walton Van Winkle: Water Supply Papers, U. S. Geol. Survey, pp. 237, 339, and 363.

silica. The forty-five streams in the eastern part of the United States that show more than 10 per cent silica have an average of 102 parts per million of the total dissolved solids, of which 19.2 parts are silica.

Sufficient evidence has been cited to indicate that most streams draining areas of heterogeneous rocks are high in silica. The single analysis available of the present streams in the area under discussion shows only 8 per cent of silica, but the data given above indicate that not improbably the amount of silica in the streams of the past was much higher. It is not necessary that there should have been a larger amount of silica, however, for quantitative estimates of the amount of silica in the oolitic beds indicate that the present percentage, 8 per cent, would be adequate for the formation of the oolites.

Cause of the Precipitation of the colloidal Silica as Oolites

It is well known that silicic acid, the form of the colloidal silica in streams, is readily coagulated on mingling with an electrolyte. Such an electrolyte would be furnished by the brackish or saline waters of the sea into which the streams were emptying. An excessive amount of salts in the water would cause rapid coagulation, which would result in the production of oolites. A series of experiments to determine the extent to which ordinary sea-water would coagulate the amount of silica in solution in streams, made in connection with the writer's studies on the origin of chert,[13] showed that silica is rapidly removed from the sea-water as it is added by the streams. This coagulated silica is thrown down on the sea-bottom, and through surface tension assumes a spherical form. These spherical forms are the result of the aggregation of the silicic gel molecules which are said by Tolman[14] to be 30,000 times as large as the ordinary molecule. Possibly this coagulation and rounding would be aided also by the agitation of the waters, as is suggested by Linck and others.

These rounded masses would grow as they settled through the water and after they came to rest on the bottom. The smaller oolitic grains apparently represent the first product of the coagulation of the silica. Their remarkably uniform size, amount, and distribution all favor this view. As a rule, these small oolites carried down more clay than was later included in their outer layers. The later growth occurred wherever silica was sufficiently abundant in the adjacent clay. If this rate of growth was slow, then well defined rings resulted, but if the rate was fast no rings resulted. Factors controlling this growth would be variations (*a*) in the

[13] W. A. Tarr: Am. Jour. Sci., 4th ser., vol. 44, 1917, pp. 409-452.
[14] C. F. Tolman, Jr., and J. D. Clark: Econ. Geol., vol. 9, 1914, p. 561.

distribution of the silica in the water, (*b*) in the salinity of the water, and (*c*) in the rate of accumulation of mud and sand. That the large oolites are merely the result of growth of the small ones is shown by the central zones of the larger ones being the same size as the smaller oolites. The outer surfaces of the oolites are rough, because the oolites were buried so fast that they could not be smoothed by current or wave action.

Conclusion

The oolites in the shale constituting the Popo Agie beds are believed to be due to the direct precipitation of colloidal silica introduced into the saline, shallow waters by the streams flowing from the adjacent land areas. Proof of their original character is the uniform distribution of the oolites through the shale, the distribution of sand grains through the oolites and the matrix, all lack of growth effects in the oolites, the interference of the oolites (never seen in calcareous oolites), the slight compression of the shale and flattening of the oolites, and the precipitation of the oolites in shallow, agitated water.

The precipitation of the silica was probably due to the electrolytic and saline character of the water, the resulting siliceous gel aggregating into the oolites, which were buried as the silts and sands accumulated.

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CONTENTS

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

MESOZOIC HISTORY OF MEXICO, CENTRAL AMERICA, AND THE WEST INDIES [1]

BY T. W. STANTON

(*Read before the Paleontological Society January 1, 1918*)

CONTENTS

Introduction

This résumé deals only with those phases of Mesozoic history which have a direct bearing on the biologic relationships of North and South America by indicating on the one hand epochs of probable marine connection between the Pacific and the Atlantic through tropical America, and on the other hand epochs of probable land connection between North and South America. The evidence to be presented consists of the distribution of the sediments of different epochs on the present land area, their character as marine or continental, and the relationships of the marine faunas found in them. Most of the data are recorded on the Geologic Map of North America compiled by Willis and Stose, and in the literature abstracted by Willis in his Index to the Stratigraphy of North America. These have been supplemented by the consideration of more recent papers by C. Burckhardt, E. Böse, G. R. Wieland, J. P. Smith, and others, and by a few collections of fossils which have been studied by me. Through the courtesy of Professor Schuchert, I have also had the use of manuscript notes on the stratigraphy of Mexico prepared for him by E. Böse.

Our knowledge of the character and distribution of the Mesozoic faunas of Mexico has been greatly increased during the last fifteen years by the

[1] Manuscript received by the Secretary of the Society August 22, 1918.

work of Burckhardt, Böse, and other members of the Geological Institute of Mexico, but many desired details are still lacking, especially concerning southern Mexico, and the faunas and formations of the Central American States are known only in a general way. It is obvious that deductions from such incomplete data must be only tentative. Even in areas where the stratigraphy, paleontology, and areal distribution are thoroughly known, there is usually an element of doubt and uncertainty in interpreting sea and land connections. There is nearly always more than one possible explanation of the facts observed, and the most obvious explanation may not be the true one. A great difference between contemporaneous marine faunas such as is found between the Shasta fauna of the United States Pacific coast and the Comanche faunas of Texas and Mexico strongly suggests a persistent land barrier; but other conditions, such as climate, character of bottom, etcetera, may be equally effective in causing differences in faunas, and when the Comanche, or Gulf, type of sediments and fauna seems to extend entirely across southern Mexico, reaching the Pacific coast, it becomes necessary either to abandon the land barrier or to shift it westward beyond the present continental area. There is equal difficulty in establishing particular interoceanic connections. Close similarity of contemporaneous marine faunas with considerable specific identity is good evidence of an open route for migration between the two areas, but that route may not always have been the one which now looks easiest. Certain of the Triassic and Jurassic faunas of California show close relationship with the corresponding faunas of the Mediterranean province in Europe, and their relationship has very naturally been attributed to migration through the Central American portal, as J. P. Smith has called it, but the possibility of an Indo-Pacific route, or even of an Arctic route, should not be overlooked.

With these general words of caution concerning the nature of the data and the conclusions that may be placed upon them, we may proceed to sketch the oscillations of land and sea in Mexico and Central America during the Mesozoic era, beginning with early Triassic time.

Triassic

The Triassic was in general a period of emergence for the North American Continent. Practically the whole of the continent was above sealevel most of the time, and the minor recorded changes in strand-line in the area north of Mexico affected only the Pacific coast. Marine Lower Triassic deposits are known only in eastern California, Utah, and southeastern Idaho, probably extending into western Wyoming. The earliest fauna in these beds, the *Meekoceras* fauna, is Asiatic in its affini-

ties, its nearest relatives being found in India and Siberia. It is therefore a reasonable inference, both from the faunal relationship and the areal distribution of the deposits, that there was no direct connection between Atlantic and Pacific waters through the Mexican-Central American region. A later fauna in the Lower Triassic, the Tirolitic fauna, is known only in the Mediterranean region and in Idaho, and hence an open route of migration through the Central American region has been inferred, but no deposits or other direct evidence in support of this inference are known.

The facts are similar for the Middle Triassic when the sea retreated still farther, so that the known marine deposits are restricted to eastern California, central Nevada, and British Columbia. In his recent monograph of the Middle Triassic marine invertebrate faunas of North America, J. P. Smith states that "the faunas of the American and of the Mediterranean regions during the Middle Triassic are more closely related to each other than either is to the Indian or to the Boreal fauna." He further says that "in the zone of *Ceratites trinodosus,* in the West Humboldt Range of Nevada, out of more than 100 species more than one-fourth are either identical with or very closely related to forms from this zone in the Mediterranean region. It is possible that during the Middle Triassic a connection was established between these regions through some other way than the Indian branch of the old central Mediterranean, or 'Tethys.'" In another paper he definitely states that the Central American portal was reopened at this time. Again, the oceanic connection is based on faunal relationships of distant regions only.

During Upper Triassic time the Mediterranean element in the California faunas continues large and is especially predominant in the *Tropites subbullatus* fauna of the Hosselkus limestone, which is referred to the Karnic epoch. The only marine Triassic deposits known in North America south of the United States are also of Karnic age and have yielded a meager fauna which is closely related to that of the Mediterranean on the one hand and to that of California on the other. These beds are in central Mexico, near the city of Zacatecas, with possibly another area southeast in Guanajuato. On account of these faunal and geographic relations, Burckhardt has suggested a marine connection between the Atlantic and Pacific across central Mexico, and Smith has inferred an open "Central American portal." That there was a passage somewhere between Panama and central Mexico seems reasonable.

The Upper Triassic submergence was of brief duration, and not long thereafter, either in latest Triassic or earliest Jurassic time, or possibly in both, there was an epoch of continental sedimentation during which,

in several widely distributed areas, cycads and other land plants were embedded in non-marine deposits. Newberry has described some of these plants from Honduras and from Sonora as Rhætic, and somewhat similar floras have been described by Logano as Lower Jurassic (Liassic) from the States of Vera Cruz and Puebla, and by Wieland from the State of Oaxaca. Non-marine deposits similar to those containing the plants are distributed through Chiapas, Guatemala, Honduras, and Nicaragua. (Incidentally it should be mentioned that in Willis's Index to the Stratigraphy of North America, page 500, through an error in transcription or proof-reading, Sapper is made to call these rocks *marine*. The original word is Mergel, which of course was translated marls.) The length of the epoch or epochs represented by these plant-bearing deposits and their exact place in the general time scale must be determined by further studies and discussions by the paleobotanists, supplemented by thorough investigation of the stratigraphy of each area involved. Meanwhile these floras may be used as proof of extensive land areas near the close of the Triassic and continuing into Jurassic time.

Jurassic

That the plant-bearing beds of southern Mexico just mentioned are actually of Jurassic age seems to be established by their association with marine beds containing characteristic Jurassic ammonites. According to Böse, those of Puebla are lower Liassic, while those of Oaxaca described by Wieland are in part Middle Jurassic, perhaps extending down into the Upper Liassic. Böse reports marine Liassic beds with *Arietites* and a varied molluscan fauna in northern Puebla and neighboring parts of Hidalgo and Vera Cruz at elevations of over 2,000 meters, and another possible occurrence of marine Liassic in Oaxaca. All the other known areas of marine Lower Jurassic in North America are confined to the Pacific border north of Mexico, and the imperfectly known fauna seems to be sufficiently related to that of Europe to indicate direct connection. The marine deposits in southern Mexico strongly suggest that the interoceanic passage was in that region.

Similar conditions prevailed in Middle Jurassic time, when the faunas of the Pacific coast of the United States were related to those of the Mediterranean region, and the presence of marine Middle Jurassic sediments in Oaxaca and Guerrero indicates that the interoceanic connection may have been across southern Mexico.

The wider distribution of Upper Jurassic sediments in Mexico, in Cuba, and in west Texas seems to indicate a greater submergence than at any previous epoch in the Mesozoic era. Marine rocks of Upper Jurassic

age are found in Chihuahua, Durango, Nuevo Leon, Zacatecas, San Luis Potosi, Puebla, Guerrero, Oaxaca, and the Isthmus of Tehuantepec, and include Oxfordian, Kimmeridgian, and Portlandian. According to Burckhardt, the faunas are related to those of central Europe and the Mediterranean, but also include elements derived from the faunas of India, of the boreal region, and of the Andes, together with a characteristic element which may be called Mexican. This Mexican element seems to be represented in the Jurassic of western Cuba, which is the oldest known Mesozoic of the West Indies. A reasonable interpretation includes the Mexican and Texan Upper Jurassic in the Atlantic or Gulf of Mexico sedimentation, with one or more temporary connections with the Pacific to admit the boreal and Indian elements of the fauna.

Cretaceous

Cretaceous limestones with minor shales and sandstones have a great thickness and wide distribution in Mexico and Central America. Much the larger part of them are referred to the Comanche series by American geologists, and assigned to the Lower Cretaceous. Both the rocks and the faunas are of the same facies as the typical Comanche series of Texas, though it is recognized that some of the beds in southern Mexico are probably older than any of those in Texas. The Mexican geologists have divided these rocks into Lower and Middle Cretaceous, and all are agreed in assigning the rocks overlying the great limestones to the Upper Cretaceous. It is well known that the Comanche fauna is related to the Cretaceous fauna of the Mediterranean province and is totally distinct from any of the Shasta faunas of the Pacific coast of the United States, which must be in part contemporaneous with it. The difference is so great that a connection between the Pacific and the Gulf of Mexico has not been thought possible, in spite of the fact that the Comanche type of sediments and faunas seems to reach the present Pacific coast in southern Mexico. The difficulties in placing a land barrier west of the present west coast of Mexico and Central America are realized, for the 100-fathom line is only 10 to 100 miles off the coast, and the 1,000-fathom line is approximately parallel to it and only a few miles farther out. The fact that the 1,500-fathom line extends on the Equator out beyond the Galapagos Islands may have some significance, and the 2,000-fathom line sweeps far out opposite the Gulf of California as well as on the Equator. Though the difference in facies of both sediments and faunas in the Comanche as compared with the Shasta may be again mentioned, by way of caution, as partly accounting for differences in the faunas, it is believed that such a complete lack of common species must have been caused

by a land barrier between the Atlantic and Pacific throughout North America.

Comparatively little is known about the Cretaceous rocks of Central America which have been mapped by Willis as Lower Cretaceous in Guatemala, Honduras, Costa Rica, and Panama. Some geologists have described them as Upper Cretaceous, but from the brief statements about the fauna found in them it is inferred that they are probably Comanche.[2] No Lower Cretaceous rocks are known in the West Indies, with the possible exception of some imperfectly known beds on Trinidad.

The Upper Cretaceous faunas of the Pacific border, while complex and showing many local and temporal variations, are bound together by common species, so that in a broad sense they form a unit which is distributed from Alaska to the peninsula of Lower California. These faunas are remarkably distinct from the Upper Cretaceous faunas in and east of the Rocky Mountains, which also show considerable regional differentiation among themselves and are yet more or less bound together by relationships of various kinds. In Mexico the Pacific, or Chico, fauna is known only in Lower California, while the Gulf and Interior types of faunas do not extend much west of the meridian of El Paso, on the northern border, but are widely distributed east of that line in the northern half of Mexico. Farther south, in Puebla and Guerrero, isolated areas have been referred to the Upper Cretaceous, apparently of Atlantic type, but in general the Upper Cretaceous seems to be absent from southern Mexico. Near Cardenas, in southeastern San Luis Potosi, there is a Lower Senonian fauna, described by Böse, which differs markedly in facies from all the contemporaneous faunas of the Gulf Coastal Plain of the United States on account of the abundance of Actæonella, Rudistæ, corals, etcetera. It shows, however, close relationship with the West Indian Cretaceous fauna as developed in Cuba, Jamaica, and Santo Domingo, and also resembles the Gosau fauna of Europe.

All the known facts of faunal relationships and distribution seem to call for a continuous land during Upper Cretaceous time extending parallel with the Pacific border from British Columbia and farther north to South America. The history of the Mesozoic changes in land and sea which probably involved land connections between North and South America, or marine connections between the Gulf of Mexico and the Pacific, is epitomized in the tabular summary submitted by Doctor Vaughan.

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[2] A small collection of fossils from the Cretaceous limestones of Honduras received from Mr. R. W. Pack since these lines were written seem to belong to the Comanche fauna.

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RELATIONS BETWEEN THE MESOZOIC FLORAS OF NORTH AND SOUTH AMERICA [1]

BY F. H. KNOWLTON

(Read before the Paleontological Society December 31, 1917)

CONTENTS

INTRODUCTION

The natural order of sequence in considering the relations between the Mesozoic floras of North and South America must be the Triassic, the Jurassic, and the Cretaceous.

TRIASSIC

Rocks of Triassic age are known in many and widely separated parts of the world, and they are of great thickness, which implies a varied and relatively long-continued period of geologic activity. It is also evident from the thick deposits of coal known at several points, and in other ways, that vegetation must have been fairly abundant and considerably varied in character; yet the determinable forms of plant life that have thus far been recovered from the Triassic are surprisingly few in number—in fact, it is doubtful if the known flora far exceeds 300 species. This is, of course, to be largely attributed to the fact that much of the deposits were laid down under marine conditions, where one would hardly expect to find the remains of land plants preserved except near shore and more or less fortuitously; and, further, if the evidence believed by some to indi-

[1] Manuscript received by the Secretary of the Society August 22, 1918.

cate aridity is really valid—it is not altogether accepted—it might account to some extent for the absence of plant remains in certain very thick and generally barren deposits.

But, be these controlling factors what they may, the fact remains that the known Triassic flora is but scantily preserved to us. In addition to the scantiness of the plant remains, there is another element that must be mentioned, namely, the authenticity of the reference of certain deposits to the Triassic. Though quite generally considered as referable to this epoch, there is some lack of confirmatory data—that is, in the absence of thoroughly satisfactory information it is often difficult to decide between Upper Triassic and Lower Jurassic.

The Triassic flora of North America north of Mexico numbers 136 nominal species. Of this number about 120 species are confined to the eastern province—that is, to Massachusetts, Connecticut, Pennsylvania, Virginia, and North Carolina. The remaining 16 forms are distributed as follows: Abiquiu, New Mexico, 11 species; fossil forests of Arizona and vicinity, 4 species; and Alaska, 1 species.

Passing south into Sonora, Mexico, it is to be noted that Newberry described a small collection belonging to 9 genera and 13 species that were supposed to be in the same stratigraphic position as those at Abiquiu, New Mexico, though only one species is common to the two areas. From the so-called Mixteca Alta, or high country, on the southern edge of the Cordilleran system facing the Pacific, in the Mexican State of Oaxaca, Wieland has reported the presence of Triassic plants; but it is my opinion that these plants are younger than this, though it is not definitely settled just what their position is.

In 1888 Newberry[2] reported the presence of Rhætic plants from San Juancito, Honduras, enumerating 11 genera and 14 species. In a number of subsequent publications Carl Sapper[3] has intimated that Newberry's age determinations should be accepted only with doubt; they are possibly Jurassic.

Passing now into South America, so far as I am able to determine the first plants of supposed Triassic age were reported by Zeiller,[4] in 1875, from La Ternera, northern Chile. They were found in a rather important coal-basin and comprise only six species, belonging to the genera *Jeanpaulia, Angiopteridium, Pecopteris, Dictyophyllum, Podozamites,* and *Palissya;* they were referred to the Rhætic.

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[2] J. S. Newberry: Am. Jour. Sci., 3d ser., vol. 36, 1888, pp. 342-351.

[3] Bol. Inst. geol. Mexico, no. 3, 1896, pp. 5-8.

[4] R. Zeiller: Note sur les plantes, fossiles de la Ternera (Chili). Bull. Soc. geol. de France, 3d ser., vol. 3, 1875, pp. 572-574.

In 1899 Solms-Laubach[5] reported on a much larger collection from the same locality. He was able to enumerate about a dozen genera, but did not give specific names to all. They were still considered to be of Rhætic age.

About the same time that the discovery of Triassic plants was made in Chile, plants presumed to be of the same age came to light in Argentina. They were first reported on by Geinitz,[6] in 1876. He enumerated 14 species, referred to 12 genera. Only one or two of the forms are identical with those described from Chile.

A few years later Szajnoche[7] described a small flora of 11 species, referred to 8 genera, from Cachenta, in the Province of Mendoza. Only two species appear to be identical with those described by Geinitz. Szajnoche compares this flora with beds of similar age in Queensland, New South Wales, India, Germany, and Bjuf, in Sweden. It does not appear that any of the Argentinian forms are identified with North American species.

From this hasty review it must be very evident that the data are lacking for an adequate comparison of the Triassic floras of North, Central, and South America. The localities are few, are often separated by thousands of miles, and, moreover, there is still more or less doubt in some cases as to their position.

Jurassic

No Jurassic floras are at present known from eastern North America. From western North America—principally California, Oregon, and Alaska—about 125 species have been recognized. Of these, two localities—Kadiack Island and the Matanuska Valley, Alaska—with about a dozen species each, are referred to the Lias, and the remainder are referred to the Middle and Upper Jurassic. The latter find their close parallel with the well known Jurassic floras of eastern Asia.

Within the past year two small floras thought to be of Liassic age have been described by Lozano[8] from the States of Vera Cruz and Puebla, Mexico. Although certain of the forms described are seemingly abundant

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[5] H. Grafen, Solms-Laubach: Zu Beschribung der Pflanzenreste v. La Ternera. Neues Jahrb., Beilage, vol. 12, 1899, pp. 593-609, pls. 13, 14.

[6] H. B. Geinitz: Ueber Rhatische Pflanzen-und Thierreste in den argentinischen Provinzen La Rioja, San Juan und Mendoza. Palæontographica, Suppl. 3, 1876, pp. 1-14, pls. 1, 2.

[7] L. Szajnoche: Über fossile Pflanzenreste aus Cachenta in der argentinischen Republik. Sitzr. d. Akad. wiss. Wien, vol. 97, 1888, pp. 1-20, pls. 1, 2.

[8] E. D. Lozano: Description de unos plantas Liasicas de Huayacocotla, Ver., Algunas plantas de la flora Liasica de Huauchinango, Pueb. Bol. Inst. geologico de Mexico, no. 34, 1916, pp. 1-18, pls. i-ix.

and well preserved, the flora as a whole is small and poorly represented. Only eight genera are recognized, and of these several are so poorly preserved that specific identification was not attempted. A number of the forms recognized are identical with those described by Wieland[9] from the Mixteca Alta, in Oaxaca, from beds also referred to the Lias. This is a comparatively rich flora, comprising 21 genera and about 60 forms. It is especially rich in forms as well as individuals of the peculiar *Williamsonias.* This flora can hardly be accepted at its face value. It seems to me that there must have been either a mixture of horizons or a misidentification of generic types. If the genera *Noeggerathopsis, Trigonocarpus, Rhabdocarpus, Alethopteris, Sphenopteris,* and, above all, *Glossopteris,* have been correctly identified, it would certainly argue for a much older position than the Lias, and the *Williamsonias* and other types of cycads would not be out of place at a higher horizon.

The entire South American Continent is without a known locality for an undoubted or at least adequate Jurassic flora. As already pointed out, the floras from Chile and Argentina above referred to the Triassic may possibly be referable in whole or in part to the Lias instead of the Rhætic, but further data must be forthcoming before the matter can be settled. Thus, from Piedra Pintada, on the northern border of Patagonia, Kurtz has described a small collection of plants procured by Roth. They are associated in beds with marine fossils considered to be of Liassic age. Kurtz has compared the plants with the Rajmahal flora of the Upper Gondwanas of India.

The largest and by all odds the most interesting Jurassic flora is really extralimital. This is the Middle Jurassic flora described by Halle[10] from Hope Bay, Graham Land, 63° 15′ south, and just outside the Antarctic Circle. It embraces 61 forms, of which number 21 are definitely identified with previously known forms, and of these 17 are found elsewhere in strata believed to be of Middle Jurassic age, although it includes some types that are older and some that might be younger. The closest affiliation of this flora is shown to be with the well known Jurassic of Yorkshire, England, there being no less than 9 of the 21 species in common. There are no South American floras of any importance that can be considered contemporaneous with this Graham Land flora.

Possibly contemporaneous with the Graham Land deposit is a collec-

[9] G. R. Wieland: La flora Liasica de la Mixteca Alta. Bol. Inst. geologico de Mexico, no. 31, 1914.

[10] T. G. Halle: The Mesozoic flora of Graham Land. Wissen. Ergebnisee d. Schwedinschen Südpolar-Exped. 1901-1903, vol. 3, no. 14, 1913.

tion described by Halle[11] from Bahia Tekenika, Tierra del Fuego, which is about 60 nautical miles northwest of Cape Horn. It comprises only two generic types (*Sphenopteris* or *Coniopteris* and *Dictyozamites*), neither of which was sufficiently well preserved to admit of specific determination. It can not have very much weight in the present connection.

Cretaceous

Just as it has been found difficult on the basis of available data to distinguish between Triassic and Jurassic, so is it difficult to decide between Jurassic and Cretaceous. Thus, from middle Peru, Neumann[12] enumerated seven species which he held to be of Wealden age, although they include some apparently Upper Jurassic elements. The same year Lukis mentioned three poorly preserved species of plants from a coal mine near the same locality as those mentioned by Neumann, referring them to the Neocomian. Later, in 1910, Salfeld[13] procured about a dozen species of plants from the same general area, referring them in part to the extreme Upper Jurassic and in part to the lowest Cretaceous. Halle has expressed the opinion that they are probably all to be best regarded as lowest Cretaceous; also transitional between the Jurassic and Cretaceous, or possibly belonging wholly to the latter, is a small collection described by Halle[14] from Lago San Martin, central Patagonia. It embraces about twelve generic types and a slightly larger number of species. Some are older in affinity as some are somewhat younger, but on the whole Halle concludes that there is nothing to militate seriously against their extreme Lower Cretaceous age.

One of the most important discoveries bearing on the present discussion was that of an extensive dicotyledonous flora at Cerro Guido, Province of Santa Cruz, Argentina. This flora was listed in a short, unillustrated paper published by Kurtz[15] in 1902. It enumerated 31 forms, of which 21, or 75 per cent, are characteristic types of the Dakota group. Although these plants have never been figured, and it is consequently impossible to check up the identifications, they are mostly such characteristic species

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[11] T. G. Halle: Kungl. Svenska Vetensk. Handl., vol. 51, 1913, no. 3, pp. 6-12.

[12] Richard Neumann: Beitrage zur Kentniss der Kreidformation in Mittle-Peru. Neues Jahrb., Beilage, vol. 24, 1907, pp. 69-132.

[13] H. Salfeld: Fossile Pflanzen aus dem obersten Jura, bzw. der untersten Kreide von Peru. Wissen. ver offenntich. d. gesell. f. Erdkunde, Leipzig, vol. 7, 1911, pp. 211-217.

[14] T. G. Halle: Kungl. Svenska Vet.-Akad. Handl., vol. 51, no. 3, 1913.

[15] F. Kurtz: Contribiciones à la palæophytologia Argentina. Sobre la existencia de una Dakota flora en la Patagonia austro-central, Revista Museo La Platà, vol. 10 (1899), 1902, pp. 43-60.

that it is hardly possible to suppose that all or even any considerable percentage have been incorrectly determined. Therefore, taking the list at its face value, it might well enough have been made of a collection from the Dakota of Kansas or Nebraska. In the 5,000 miles between Kansas and this locality in Argentina no trace of this flora has been reported. Argentine geologists regard these beds as Cenomanian; but, as Berry, Halle, and others have suggested, they are probably not older than Turonian.

Summary

With the exception of the Dakota flora from Argentina just mentioned, there is comparatively little demonstrable relationship between the Mesozoic floras of North and South America. The total known Triassic flora from South America hardly exceeds 30 species, and of these no more than two or three are specifically identical with North American forms, though it is but fair to state that when the floras of the two continents come to be revised in the light of existing knowledge more species will probably be found to be common to the two. As the matter now stands, a majority of the South American species are regarded as endemic, and many of the others are either questionably identified or referred to Old World species.

Demonstrable specific relationship between the Jurassic floras of North and South America is, if possible, less satisfactory than in regard to the Triassic floras. The Jurassic floras on the South American Continent are so fragmentary and generally unsatisfactory that it is hardly worth while to attempt comparisons. The only flora of importance is the extralimital one found on Graham Land. This and such as we know from South America are clearly but integral parts of the great world-ranging Jurassic floras. In fact, remoteness appears to have had little influence on distribution. Witness this Graham Land flora, which finds its closest relationship with that of Yorkshire, England, and important relationship with other parts of Europe as well as India, and, it may be added, it is not greatly different from the well known Jurassic floras of California, Oregon, Alaska, and Siberia.

The relationship between the Upper Cretaceous Dakota group flora of Argentina and the Dakota flora of Texas, Kansas, and Nebraska is direct and positive. The now dominant group of dicotyledons clearly originated in the north, and in late Lower Cretaceous time had spread south over eastern North America and western Europe. By latest Lower Cretaceous and early Upper Cretaceous time they had spread west in North America,

to become the Dakota flora of the central Western States. This Dakota flora undoubtedly spread southward to find its southernmost known limit in Argentina. The pathway between these areas, although now largely buried beneath later sediments, was undoubtedly open in Upper Cretaceous time. The presence in the Argentine "Dakota" flora of a very few elements of possibly later age may be sufficient to make it slightly younger than the principal Dakota floras of the north—that is, it may have taken an appreciable time for its journey, and it may not have reached there until early Turonian time.

A word may be said as to the possible, not to say probable, routes by which the Triassic and Jurassic floras reached South America. It is necessary to review briefly the plant distribution during Permo-Carboniferous time in order to get a proper perspective. In Permo-Carboniferous time the world was divided into two phytogeographic provinces—a northern and a southern—and there was extremely little commingling of plant types between them. The southern province, characterized by the so-called *Glossopteris* flora, embraced portions of India, Australasia, South Africa, Antarctica, and eastern South America. It reached the northern province at a single point in north central Russia. It has been found within 5 degrees of the South Pole. To my mind the facts all point to the origin of this flora in the south, either in Australia or on the Antarctic land-mass, and I believe there was in Permo-Carboniferous time a practically continuous land connection between the Antarctic Continent (Gondwana Land) and south Africa, Australia, India, and South America. Any attempt to derive the *Glossopteris* flora of Brazil, the Falkland Islands, and Buckley Island (85 degrees south) from the north by way of North America is without supporting data.

Some students—notably Ettingshausen—have held that the differences between the northern and southern phytogeographic provinces that are so marked in Permo-Carboniferous time continued well into the Jurassic. This appears to be true only in part, for while there are some notable differences in the floras of the two areas, the differences are by no means so sharp as in Permo-Carboniferous time. For example, the Ginkgoales, a dominant and widespread group of the north, did not reach the southern province, and *Podozamites,* abundant in the north, is but sparsely represented in the south. From available data it appears that at least the major portion of the early Mesozoic flora originated in the north, whence they spread pretty much over the globe. Their routes of travel are not always clear, however. It is possible that the Jurassic flora found on Graham Land may have reached this far southern point by way of North

America, Central America, and the entire length of South America; but the fact that the obvious affinity of this flora is with the floras of India, Europe, and thence to England, rather than with western America, leads me to think it at least possible that the land bridge over Antarctica was still existent.

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GEOLOGIC HISTORY OF CENTRAL AMERICA AND THE WEST INDIES DURING CENOZOIC TIME[1]

BY THOMAS WAYLAND VAUGHAN

(*Read before the Paleontological Society January 1, 1918*)

CONTENTS

INTRODUCTION

During the past two or three years several papers of unusual importance, in my opinion, have appeared on the geographic distribution of terrestrial organisms. These include "Climate and evolution,"[2] by W. D. Matthew; "The development of the natural order Myrtacecæ,"[3] "The

[1] Manuscript received by the Secretary of the Society August 22, 1918.

The article herewith presented is based upon a paper by me, entitled "The biologic character and geologic correlation of the sedimentary formations of Panama in relation to the geologic history of Central America and the West Indies," now in page proof, as the closing part of Bulletin 103 of the U. S. National Museum, which bears the general title "Contributions to the geology and paleontology of the Canal Zone, Panama, and geologically related areas in Central America and the West Indies." The two correlation tables contained in the present article have been published in the Journal of the Washington Academy of Sciences, vol. 8, no. 9, May 4, 1918, pp. 272-275.

[2] New York Acad. Sci. Ann., vol. 24, 1915, pp. 171-318.

[3] New South Wales Linn. Soc. Proc., vol. 38, 1913, pp. 529-568.

development and distribution of the natural order Luguminosæ,"[4] and "The geological history of the Australian flowering plants,"[5] by C. E. Andrews; and "Plants, seeds, and currents in the West Indies and Azores," by H. B. Guppy.[6] These three authors agree in their main thesis, namely, that vertebrates and plants have spread from northern areas radially southward over Africa, South America, southeastern Asia, Malaysia, and Australasia. They all deny direct land connection, at least since Paleozoic or early Mesozoic time, between Africa and South America and between South America and Australia, and they question there ever having been any such bridges. Furthermore, they all agree, explicitly or implicitly, in the essential permanence of the continents and of the great oceanic basins. There are other points of agreement, but these are the ones I wish particularly to emphasize in this connection. Although I may not accept every detail of the conclusions of these authors, it is my belief that their main contention is incontrovertible.

All geologic evidence known to me supports the theory of the permanence of continents and oceanic basins, but the validity of this theory does not exclude there having been great differential crustal movements in some areas. As I shall speak of certain earth blocks that, in my opinion, have changed their position with reference to sealevel, I wish to remind you that faults and folds causing great vertical and horizontal displacement of strata now above sealevel are known to all geologists, and that it is reasonable to expect in other areas of disturbance that downthrown blocks or the synclines of folds lie below, while only the upthrown blocks or the anticlines stand above ocean level.

Geographic Relations of the three Americas

The boundaries of the Gulf of Mexico and the Caribbean Sea form a parallelogram; those on the north and south extend along east and west lines, those on the east and west are northwest to southeast, while the basins are separated by east and west structures. There are two landlocked basins, except that between Florida and Trinidad relatively shallow passages between land areas connect with the Atlantic Ocean. The two basins are separated by structures transverse to the continental trend in Yucatan and Cuba, and the Gulf of Mexico is a simple while the Caribbean Sea is a compound basin.

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[4] New South Wales Roy. Soc. Proc., vol. 48, 1914, pp. 333-407.

[5] Amer. Jour. Sci., 4th ser., vol. 42, 1916, pp. 171-232.

[6] Published by Williams and Norgate, London, 1917, pp. 531, 3 maps and a frontispiece.

Twelve major tectonic provinces, with several subordinate provinces, may be discriminated, as follows:

1. Bahamas.
2. Atlantic and Gulf Coastal Plain.
3. Mexican Plateau.
4. Oaxaca-Guerrero.
5. Yucatan.
6. Guatemala-Chiapas.
7. Cuba and northern Haiti.
8. Honduras and its continuation to Jamaica, southern Haiti, Porto Rico, the Virgin Islands, and the outlying island of Saint Croix.
9. Costa Rica-Panama.
10. Andes.
11. Maritime Andes.
12. Caribbean Islands.
    12*a*. Barbadian Ridge.
    12*b*. Main Caribbean Arc.
    12*c*. Aves Ridge.

Of these provinces, (1) the Bahamas, (2) the Atlantic and Gulf Coastal Plain, and (3) the Mexican Plateau will be only mentioned, but the others will be briefly described.

4. Oaxaca-Guerrero: A structural axis extends through Michoacan, Guerrero, and Oaxaca, almost at right angles to the trend of the Mexican Plateau. The northern boundary of this province is the escarpment at the southern margin of the Mexican Plateau; the western and southern boundary is the Pacific Ocean, while the eastern boundary is the Isthmus of Tehuantepec. It is thus set off from the Mexican Plateau and the Yucatan lowland.

5. Yucatan: This province consists of lowlands under 600 meters in height, underlain by only slightly deformed Tertiary strata, except some problematic rocks west of Belize. The Yucatan Peninsula and Campeche Bank are comparable to the Floridian Plateau. They are developed along a structural axis almost at right angles to the continental trend. Campeche Bank projects northward from the shoreline of the peninsula 170 nautical miles to the 100-fathom curve, and has a width of nearly 360 nautical miles along an east and west line. On the east the depth of water between it and Cuba exceeds 1,000 fathoms and the axial trends are not coincident, but the axis of Yucatan Bank and that of the Province of Pinar del Rio, Cuba, curve so that they are nearly parallel, with a trough, Yucatan Channel, between them.

6. Guatemala-Chiapas: This province lies between the Yucatan lowland on the north and Rio Motagua on the south. It is an upland domi-

nated by east and west tectonic lines, and has been called the Guatemala-Chiapas Plateau by Tower.[7]

7. Cuba: This province is coincident with Cuba and its submarine continuation, the Cayman Ridge. At least four subdivisions should be recognized: (1) The Isle of Pines, which is composed of mountains of schists and marbles with piedmont plains and marsh, separated from the main island by water less than ten fathoms deep. (2) Organos Mountains of Pinar del Rio and the accompanying piedmont plains. The 1,000-fathom curve is less than 20 miles off the north shore. (3) Central Cuba, from the east end of Organos Mountain to Cauto River, is mostly a plain broken by some hills of serpentine and granite, and in Santa Clara Province, near Trinidad, mountains reported to be composed of Paleozoic sediments attain an altitude of about 2,000 feet. (4) Sierra Maestra and Cayman Ridge. This subprovince lies between the Cauto Valley and the south shore and is continued westward as the submarine Cayman Ridge, along the axis of which only the Cayman Islands project above water level. The axial trend is nearly east and west between Cabo Cruz, Cuba, and Little Cayman, whence it curves to the southwest and pitches toward the head of the Gulf of Honduras, which is an area of depression. Between the Caymans and the Isle of Pines the depth of water exceeds 1,000 fathoms, while the Bartlett Deep to the south, separating Cuba and Jamaica, exceeds 3,000 fathoms in depth.

7a. Haiti, northern part: The Island of Haiti lies at the convergence of the trend of the axis of the central subprovince of Cuba and the Honduras-Jamaican axis. The dividing line in Haiti is from Port au Prince to Ocoa Bay. The area south of this line belongs to a Jamaican axis, while that to the north belongs to the central Cuban trend. The structural axes of the mountains in the northern and northeastern part of Haiti are from northwest to southeast and are parallel to the axis of elongation of Cuba from the Sierra Maestra to Santa Clara. In Cuba this trend is cut diagonally by the axis of the Sierra Maestra, which is bounded on the south by a tremendous fault-scarp. Previous to this faulting it seems that central Cuba and Haiti formed parts of the same land area. The Island of Haiti might be treated as separate from Cuba and Jamaica, but lying at the intersection of two tectonic trends.

8. Honduras and the Jamaican Ridge: The Honduran Province in Central America is dominated by tectonic lines extending from southwest to northeast, of which Telusa Mountains are representative. A line from the Gulf of Honduras along Motagua River to a point north of Jalapa,

[7] W. L. Tower: Investigation of evolution in chrysomelid beetles of the genus *Leptinotarsa:* Carnegie Inst. Washington, Pub. No. 48, 1906, p. 50.

thence southwest to the Pacific coast, may be taken as the northern boundary and Rio San Juan and the southern side of Lake Nicaragua as the southern boundary.

From the northeast coast of Honduras and Nicaragua a great submarine plateau continues, with depths of less than 1,000 fathoms, to Jamaica. Above it rises numerous banks and keys and along its course are Thunder Knoll, Rosalind, Seranilla, and Pedro banks between the continental shore and Jamaica.

The principal old tectonic lines of Jamaica trend northwest to southeast. As these are parallel to the shore northwest of Cape Gracias a Dios and to the northeast edge of Mosquito Bank, there are evidently cross-tectonic lines nearly at right angles to each other in this ridge.

A submarine ridge extends some 45 miles from the east end of Jamaica and overlaps on the south side a ridge which protrudes westward from the west end of Haiti. The two ridges, however, do not connect, but are separated by water over 1,000 fathoms deep. The ridge representing an eastward submarine continuation of Jamaica indicates a third tectonic line in that island. The last mentioned line nearly parallels the Bartlett Deep, which lies to the north. The submarine slopes to the southeast are toward the bottom of the Caribbean basin.

8*a*. Haiti (southern part), Porto Rico, and the Virgin Islands: The political division of Haiti designated Sud is dominated by east and west trending mountains, which parallel in direction the east and west axis of Jamaica. As the maximum depth between Haiti and Porto Rico is about 318 fathoms, they rise from a common, not greatly submerged, bank. (See statement on preceding page in regard to considering Haiti as a separate province.)

The main mountain mass of Porto Rico, the Sierra Central, the maximum altitude of which is 3,750 feet at El Yunque, trends east and west, paralleling in direction Sud, Haiti. There is coincidence in the direction of elongation of the Jamaican bank, Sud (Haiti), and Porto Rico.

The relative truncation of the west end of Porto Rico, except the protuberant which forms Cabo de San Francisco, is striking and suggests faulting. The declivities both to the north and south of the island are great, over 4,000 fathoms in depth being reached within 40 miles of the north coast, while 2,000 fathoms are attained within a shorter distance from the south coast.

A submarine bank extending from the east end of Porto Rico to Anegada Passage is known as Virgin Bank. The depth of water between the islands rising above this bank is less than 20 fathoms, which is a maximum for the amount of submergence they have recently (geologically speaking) undergone. These islands are detached outliers of Porto Rico.

8*b*. Saint Croix: Although Saint Croix is separated from the Virgin Islands by a depth as great as 2,400 fathoms and is joined to the Saint Christopher chain by a ridge less than 1,000 fathoms deep, it possesses great similarity to members of the Virgin group. The west end is truncate and the submarine slope precipitous; the submarine slope to the north is also steep. There is clear evidence of faulting on the west and north sides. A ridge, largely of igneous rock, stands against the north shore from the west end of the island for some distance to the east. South of the ridge is a sloping, rolling, calcareous plain. The east end has a submarine continuation in a bank less than 50 fathoms deep. The tectonic axis is east and west, the rocks resemble those of the Virgins, and the zeogeography indicates former connection with them. For these reasons it seems probable that this island was formerly a part of the Porto Rican-Virgin Island land-mass and has been sundered from it by diastrophic processes. However, Saint Croix might be accorded separate status as a province, or referred to the Saint Christopher axis; but it appears to me preferable to classify it with the Virgin Islands.

9. Costa Rica-Panama: Between the Nicaragua-Costa Rican boundary and the mouth of Rio Atrato is an S-shaped land area which does not exhibit striking tectonic lines, although some deformation axes are obvious in Panama. The region is largely one of vulcanism, present or past, which, although occurring within limits, does not follow continuous straight axes, but occurs in a curving belt. The topography appears disordered, with volcanic protuberants here and there without perceptible system. The volcanic heaps range from a few hundred to nearly 10,000 feet in altitude.

10. Andes: The south-north trending ranges of the Andes reach the shores of the Caribbean Sea between the gulf of Darien and Venezuela, and send a spur, Cordillera de Merida, northeastward to Porto Cabello, where the main Andean trend is crossed by that of the Maritime Andes. The shore of the Caribbean Sea lies across the northern end of the Andes in a way similar to the manner in which the landward border of the Coastal Plain crosses the southwestern end of the Appalachian Mountains.

The islands of Curaçao, Arube, and Bonaire lie off the Venezuelan coast in the angle between the ends of the main Andes and the Cordillera de Merida.

11. Maritime Andes: The Maritime Andes lie along the Venezuela coast from Caracas eastward. Trinidad and Tobago are outlying islands. On the south side of these mountains is the great valley of the Orinoco.

12. Caribbean Islands: These islands lie along triple arcuate ridges, the Barbadian Ridge, the main Caribbean Arc, and Aves Ridge, the second of which is double at its northern end.

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12*a*. Barbadian Ridge: As Barbados is connected undersea with Tobago Island by a ridge less than 1,000 fathoms deep, and as the depth between it and Saint Lucia is less than 1,000 fathoms, there is a closed basin over 1,000 fathoms deep between the Barbadian Ridge and the main Caribbean Arc.

12*b*. Caribbean Arc: The Caribbean Arc is a ridge that extends from north of the Gulf of Paria to Anegada Passage. The islands occurring along it from the Grenadines to Dominica are entirely or predominantly volcanic. Guadeloupe is a compound island; the western half is volcanic; the eastern half, with the outlying Marie Galante, is mostly composed of calcareous sediments. North of Martinique the arc splits; along the inner fork are the volcanic islands Montserrat, the members of the Saint Christopher Chain, and Saba; along the outer fork are Antigua and Barbuda, and the Saint Martin group. The latter islands are largely or predominantly composed of sedimentary rocks resting on an igneous basement of pre-Tertiary or early Tertiary age.

12*c*. Aves Ridge: This ridge takes its name from Aves Island, which stands on a ridge running from the north coast of Cumana to Saba Island at depths slightly less than 1,000 fathoms, while water of greater depth occurs both east and west of it.

Correlation of the Tertiary Formations of the south Atlantic and eastern Gulf Coastal Plain

The accompanying table indicates the present status of the correlation of these formations, and, although it may have to be modified to accord with the results of additional investigations, there is every reason to believe that subsequent changes will be only in matters of minor refinement. However, I wish to say that I believe four paleontologic zones will be discriminated and defined in the Chattahoochee formation, and that the collections on which to base these subdivisions have already been made and in large part described, but I will not take the time to discuss these details. I also confidently expect the Ocala limestone to be subdivided into two or more zones, for the genus *Orthophragmina*, so abundantly represented in the lower part of the formation, appears to be absent in the upper beds.

Correlation of the Tertiary sedimentary Formations of Panama and the West Indies

A summary of these correlations is given on the accompanying table. Only one point appears to need special comment—that is, whether the

A PROVISIONAL CORRELATION TABLE OF THE TERTIARY FORMATIONS OF THE SOUTH ATLANTIC AND EASTERN GULF COASTAL PLAINS OF THE UNITED STATES

Age of deposits		North Carolina (South of Hatteras axis)	South Carolina (Santee drainage)	South Carolina and Georgia (Savannah drainage)	Georgia (Chattahoochee drainage)	Florida	Alabama	Mississippi	Louisiana
Pliocene		Waccamaw marl	Waccamaw marl	(Not recognized)		Caloosahatchee marl, Nashua marl, Alachua clay, and Bone Valley gravel (largely contemporaneous) | Citronelle formation	Citronelle formation	Citronelle formation	Citronelle formation
Miocene	upper	Duplin marl Unconformity	Duplin marl —Unconformity— Edisto marl	Duplin marl —Unconformity— Marks Head marl		Jacksonville formation | Choctawhatchee marl	Pascagoula clay	Pascagoula clay	Pascagoula clay
	middle			—Unconformity—		—Unconformity—			
	lower			Alum Bluff formation	Alum Bluff formation	Alum Bluff formation: Shoal River marl member Oak Grove sand member Chipola marl member	Alum Bluff formation | Hattiesburg clay	Hattiesburg clay	Hattiesburg clay
Oligocene	upper middle			Chattahoochee formation	Chattahoochee formation —Unconformity—	Tampa formation | Chattahoochee formation	Chattahoochee formation | Catahoula sandstone	Catahoula sandstone	Catahoula sandstone
	lower			Vicksburg formation	Vicksburg formation	Vicksburg group: Marianna limestone (western Florida)	Vicksburg group: Marianna limestone (with Glendon limestone member) Red Bluff clay	Vicksburg group: Byram calc. marl Marianna limestone (with Glendon limestone and Mint Spring calcareous marl members) Red Bluff clay	Vicksburg limestone
Eocene	upper	Castle Hayne limestone Trent marl	Cooper marl | Barnwell formation	Barnwell formation (with Twiggs clay member)	Ocala limestone	Ocala limestone	Ocala limestone | Jackson formation	Jackson formation (with Yazoo clay member and Moodys calc. marl member)	Jackson formation
	middle		McBean formation	McBean formation	McBean formation	(Buried)	Claiborne group: Gosport sand Lisbon formation Tallahatta buhrstone	Claiborne group: Yegua formation Lisbon formation Tallahatta buhrstone	Claiborne group: Yegua formation St. Maurice formation
	lower		Congaree shales of Sloan Williamsburg formation	(Probably overlapped)	Wilcox formation	(Buried)	Wilcox group: Hatchetigbee formation Bashi formation Tuscahoma formation Nanafalia formation	Wilcox group: Grenada formation Holly Springs sand Ackerman formation	Wilcox formation
			Black Mingo formation	(Probably overlapped)	Midway formation	(Buried)	Midway group: Naheola formation Sucarnochee clay Clayton limestone	Midway group: Tippah sandstone of Lowe Porters Creek clay Clayton limestone absent or replaced by sand	Midway formation

limestone containing *Orthophragmina* on Haut Chagres and at David, Panama, should be referred to the uppermost Eocene or to the basal Oligocene. The Ocala limestone contains large stellate species of *Orthophragmina,* and I collected a similar species in Saint Bartholomew. Of the Eocene age of these deposits, of the typical Brito formation in Nicaragua, and of certain limestones containing *Orthophragmina* in Cuba there seems to be no reasonable doubt; but, according to Douvillé, the small stellate *Orthophragmina* (subgenus *Asterodiscus*) ranges upward into the lower Oligocene. The association of *Asterodiscus* and small, even non-stellate, species of *Orthophragmina* with species of *Lepidocyclina* that at some localities are found in association with a coral fauna of middle Oligocene affinities has inclined me to the opinion that certain peculiar species of *Orthophragmina* occur in deposits of lower Oligocene age. Doctor Cushman, however, is disposed to regard the beds in which these species of *Orthophragmina* were found as of Eocene age. At present the evidence is not decisive and additional studies are needed.

Paleogeographic Summary

IN GENERAL

As Doctor Stanton has summarized in the preceding paper of this series the Mesozoic history of Central America, Mexico, and the West Indies, and as his conclusions are incorporated in the tabular statement on page — of this paper, I need not repeat anything he has said, but regarding the Paleozoic history I will state a few of the important events.

LATE PALEOZOIC

The great Appalachian revolution occurred in late Paleozoic, Permian time, and resulted in the northern boundary of the Gulf of Mexico—the southern Appalachian, the Ouachita, and Wichita Mountains.

The east and west trend in southern Mexico and in southwestern Chiapas already existed or was developed about this time, while farther to the southeast, as Sapper has shown, Rio Motagua, in Guatemala, divides two chains of this age—one to the north, the other to the south—with spurs of a third chain farther toward the southeast. The nearly north and south trend of the Coxcomb Mountains, in British Honduras, which are composed of sediments apparently of pre-Paleozoic age, indicates that the Yucatan protuberant had been outlined in Paleozoic, perhaps early Paleozoic, time. Granitic debris in Costa Rica and Panama suggests old deformation along east and west lines in those areas. The east and west mountains of Venezuela have an old foundation and certainly date back to the Paleozoic in origin. There is evidence of old

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TENTATIVE CORRELATION TABLE FOR THE TERTIARY MARINE SEDIMENTARY FORMATIONS OF PANAMA

American time subdivisions		Panama	Jamaica	Other Antilles	Mexico and Central America	Southeastern United States	European time subdivisions
Pliocene		Toro limestone	Manchioneal formation Kingston formation	Pliocene of Guantanamo, Cuba	Pliocene of Yucatan and Limon, Costa Rica	Waccamaw marl, Nashua marl, and Caloosahatchee marl (nearly contemporaneous)	Sicilian Astian Plaisancian
Miocene	upper					Yorktown formation, Duplin marl, and Choctawhatchee marl (nearly contemporaneous)	Pontian Sarmatian
						St. Marys formation Choptank formation Calvert formation | Marks Head marl	Tortonian
	middle	Gatun formation		La Cruz marl (Cuba) | Upper horizon in Martinique | Upper horizon in Santo Domingo	Gatun formation (Costa Rica) | Pacific Coast of Nicaragua | Exposures on Isthmus of Tehuantepec		Helvetian
	lower		Bowden marl	Marl at Baracoa, Cuba | Lower horizon in Martinique | Zones G, H, and I in Santo Domingo		Alum Bluff formation { Shoal River marl member Oak Grove sand member Chipola marl member	Burdigalian
Oligocene	upper	Emperador limestone Culebra formation { Upper part of Culebra		Anguilla formation (Anguilla) and beds at many localities in Cuba	San Rafael formation	Chattahoochee formation | Tampa formation	Aquitanian Chattian
	middle	Culebra formation { Lower part of Culebra and limestone at Tonosi		Coral reef at Guantanamo, Cuba | Antigua formation (Antigua) | Pepino formation (Porto Rico) | Lower horizon in Santo Domingo			Rupelian
	lower	Limestone, with *Orthophragmina*, on Haut Chagres *a* and limestone at David (contemporaneous) | Bohio congl. *b*	Montpelier white limestone		Manzanilla, Costa Rica, and deposits with Pecten aff. *P. poulsoni* and large discoid orbitoids, Mexico	Vicksburg group { Byram calcareous marl Marianna limestone Red Bluff clay	Lattorfian (Sannoisian)
Eocene	upper		Cambridge formation Richmond formation	St. Bartholomew limestone (St. Bartholomew). Widely distributed in Cuba	Brito formation of Nicaragua (typical Brito) | Frio clay Fayette ss.	Jackson formation | Ocala limestone	Ludian (Priabonian) Bartonian
	middle	Eocene of Tonosi			Claiborne group Near the Texas border	Claiborne group { Gosport sand Lisbon formation Tallahatta buhrstone	Auversian *c* Lutetian
					Wilcox formation	Wilcox group { Hatchetigbee formation Bashi formation Tuscahoma formation Nanafalia formation	Ypresian *c* Sparnacian *c*
	lower				Midway formation	Midway group { Naheola formation Sucarnochee clay Clayton limestone	Thanetian *c* Montian *c*

a Reported by H. Douvillé and referred to "Stampien inférieur" = Vicksburgian = Lattorfian. Cushman thinks these deposits should be referred to the upper Eocene and placed opposite the Saint Bartholomew limestone in the table.

b May belong stratigraphically somewhat higher.

c Correlations proposed by E. W. Berry.

deformation in Cuba, rendering it highly probable, if not certain, that the major tectonic trends of Cuba are as old as the Paleozoic. Although no Paleozoic rocks have been identified in Jamaica, the inference appears warranted that Jamaica itself dates back to late Paleozoic, as it has been shown by Sapper that the west end of the tectonic features represented in Mosquito and Rosalind banks and Jamaica already existed in late Paleozoic time. The Cuban and Jamaican trends meet in Haiti and continue through Porto Rico to the Virgin Islands, while Saint Croix, which is closely related in its geologic features to the Virgins, was probably at one time a member of that group and has been separated from them by faulting of comparatively late geologic date. There is no direct evidence of the existence at this time of any of the Caribbean Islands, but certain relations suggest that at least parts of the Caribbean Arc may be old. Saint Croix stands on the western end of a ridge between 600 and 700 fathoms deep, on the eastern end of which is Saint Christopher. This ridge extends northward to the Saint Martin Plateau, eastward to Antigua and Barbuda, and southward from the latter islands through Guadeloupe, Saint Lucia, and the Grenadines to South America. These relations suggest that the eastern perimeter of the Caribbean basin may have been outlined in late Paleozoic time.

From the preceding statement it is evident that the principal tectonic lines of the perimeters of the Gulf of Mexico and Caribbean Sea existed at the close of the Paleozoic. The northern, western, and southern boundaries had been outlined and the major transverse trends had also been formed—the more northern through Oaxaca and Chiapas, including the northward trending Coxcomb Mountains of British Honduras; the more southern through Honduras and Nicaragua. The first may have connected along the axis of the Coxcomb Mountains with Cuba and thence with Haiti; the second probably connected with Jamaica, Haiti, Porto Rico, and the Virgin Islands, and there are vague suggestions that the Caribbean Arc also existed. As the positive and negative areas so early outlined dominated the tectonic development during later geologic time, the subsequent history consists in tracing the modification of these old features.

CENOZOIC

The Cenozoic history may be summarized as follows:

Eocene and Oligocene.—The West Indian Islands, because no old Eocene sediments are known in any of them except Trinidad, which is South American in its affinities, are supposed to have stood above sealevel at that time. In Cuba and Jamaica there are Upper Cretaceous and upper Eocene sediments without the intervention of lower Eocene deposits.

During later Eocene (Ludian) and middle and upper Oligocene (Rupelian and Aquitanian) time there was extensive submergence in the West Indies and interoceanic connection through a number of straits across Central America. There may have been interoceanic connection during lower Oligocene (Lattorfian) time, but this is not established. The maximum submergence was in middle Oligocene (Rupelian) time. Vulcanism was widespread in Central America and the Antilles during Eocene and probably also during earlier Oligocene time. The line of the great Mexican volcanoes had its inception at the close of the Cretaceous, near the beginning of the Tertiary, according to Felix and Lenk.

In Jamaica, Cuba, Saint Bartholomew, and Antigua, the later Eocene age of some of the volcanic rocks is established. There was between the upper Eocene and the middle Oligocene deposition periods great deformation in the Antilles. The folding in the principal mountains of Jamaica, the Sierra Maestra of Cuba, and apparently those of Haiti, Porto Rico, the Virgin Islands, and Saint Croix, appears to have taken place at this time. Diastrophism seems also to have been active in Chiapas, Tabasco, Petén, Guatemala, Nicaragua, Costa Rica, and Panama.

Miocene.—During older Miocene (Burdigalian) time apparently there was in places connection between the Atlantic and Pacific oceans, as is shown by deposits of this age containing fossils of Atlantic affinities on the Pacific coast of Nicaragua and at other localities in Central America, but such connections seemingly were restricted, not of wide extent, as in upper Eocene and Oligocene time.

As no upper Miocene has yet been identified in the West Indies, this is supposed to have been a period of high uplift which terminated the connection between the Atlantic and Pacific oceans. The middle and upper Oligocene and lower Miocene sediments of Mexico, Panama, Cuba, Haiti, Jamaica, Porto Rico, Anguilla, and Antigua, although deformed by tilting and faulting, are not intensely folded, as are the older sediments. According to Hill, "In mid-Tertiary time granitoid intrusions were pushed upward into the sediments of the Great Antilles, the Caribbean, Costa Rican, and Panamic regions." The information I obtained in Antigua and Saint Bartholomew accords with this opinion.

That there was at some place interoceanic connection subsequent to lower Miocene (Burdigalian) time is suggested, if not actually proven, by the presence on Carrizo Creek, Imperial County, California, of a coral fauna of post-Miocene affinities.[8]

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[8] T. W. Vaughan: The reef-coral fauna of Carrizo Creek, Imperial County, California, etc., U. S. Geol. Survey Prof. Paper 98, 1917, pp. 355-386, pls. 92-102.

Roy S. Dickerson,[9] in the paper cited below, says regarding my conclusion that the coral fauna of Carrizo Creek is of probably Pliocene age: "His [Vaughan's] conclusions concerning the Pliocene age of these beds rests upon the infirm basis of comparison with a Pliocene coral fauna of Florida," and "All the coral genera except one occur in the Bowden or associated horizons." The last statement is correct, and the first is correct in that I compared the fauna from Carrizo Creek with that from the Pliocene Caloosahatchee marl of Florida; but Doctor Dickerson evidently did not comprehend the entire basis for my opinion. The following genera, now extinct in the Atlantic Ocean, but living in the Indo-Pacific, occur in the Bowden marl and related zones, but are not known from Carrizo Creek or from the Caloosahatchee marl:

Placocyathus	Antillia
Placotrochus	Syzygophyllia
Stylophora	Pavona[10]
Pocillopora	Goniopora

Neither the coral fauna of Carrizo Creek nor that of the Caloosahatchee marl, as at present known, contains any of the coral genera distinctive of the Bowden and related zones. These distinctive genera became extinct in the Atlantic during upper Miocene time, according to present information. It therefore seems to me more probable that the fauna of Carrizo Creek migrated to the head of the Gulf of California after these forms had become extinct than that they were eliminated after migration at an earlier period.

Pliocene and later.—Subsequent to the Miocene there have been many oscillations of the West Indian area, and during perhaps Pliocene time there was profound deformation. Zeogeographic data, in the opinion of several investigators, seem to demand former connection, probably during late Miocene or Pliocene time, from Yucatan across Cuba to Haiti, Porto Rico, and the Virgin Islands; from Honduras to Jamaica; and from Anguilla to South America. It also appears that Saint Croix was once joined to Anguilla and to the eastern end of the Virgin Islands. There are certain geologically late fault-lines which perhaps date from this time, and the severance of the old ridges into the islands we now know may be largely due to movement along them. One of these fault-lines forms the northern boundary of the Bartlett Deep and passes between the east end of Cuba and the west end of Haiti. Another tectonic line which forms the south side of the Bartlett Deep converges toward the former in the Wind-

[9] Ancient Panama canals. California Acad. Sci. Proc., vol. 7, 1917, pp. 197-205 (date printed with title, July 30, 1917; received by me on October 16, 1917).

[10] Added from Miss Maury's Santo Domingan collections.

ward Passage. A downthrown block between these lines has separated Cuba and Haiti and produced the Bartlett Deep. Probably there was also faulting or flexing between Cayman Ridge and the southern shore of Cuba west of Manzanillo Bay, while either faulting or flexing may have separated Cuba and Yucatan. There is evidence of a downthrown fault block between Saint Thomas and Saint Croix, the two sides converging toward Anegada Passage. This will account for the deep of over 2,400 fathoms north of Saint Croix, and the severance of Saint Croix and the Saint Martin Plateau group of islands from the Virgin group.

There are three kinds of evidence that bears on the age of these faults, namely: (1) In eastern Cuba, as the Miocene La Cruz marl is abruptly cut off at the shoreline in the vicinity of the Morro, at the mouth of Santiago Harbor, the faulting must be subsequent to old or middle Miocene; (2) as the sea along fault shores has been able subsequent to the faulting to cut only narrow benches into the fault-planes on the upthrown side, the fault-planes are physiographically young; (3) the biologic evidence, in the opinion of most of those who have recently considered it, demands land connection in late Tertiary time between Cuba, Santo Domingo, Porto Rico, and thence to South America. Miller has recently published an important paper on this subject,[11] and states:

"With the characters of so many [eight] genera known it becomes possible to gain some idea of the Antillean hystricine fauna.[12] The most noticeable feature of these genera, considered as a group, is their similarity to the Santa Cruzian and Entrerian rodents which Ameghino and Scott have described and figured. In no instance has the same genus been found in both the West Indies and Argentina or Patagonia; but the Antillean rodents thus far discovered never show such peculiarities that their remains would appear out of place among those of their extinct southern relatives, while as a whole they would at once be recognized as foreign to the present South American fauna."

On the following page of the same paper he says:

"So far as can be judged from eight[13] very distinct genera, the Antillean hystricine rodents do not present the characters that would be expected in animals derived from South America during any period geologically recent. Neither have they the appearance of an assemblage brought together at different times by migration or chance introduction. On the contrary, they suggest direct descent from such a part of a general South American fauna, probably not less ancient than that of the Miocene, as might have been isolated by a splitting off of the archipelago from the mainland. Of later influence from the continent there is no trace."

[11] Gerrit S. Miller, Jr.: Bones of mammals from Indian sites in Cuba and Santo Domingo. Smithsonian Misc. Coll., vol. 66, no. 12, 1916, 10 pp., 1 pl.

[12] Op. cit., p. 3.

[13] "Two more were described by Anthony in January, 1917. They bear out my statement about the eight and make it stronger.—G. S. M., Jr."

The mammals furnish more evidence of this kind than I am presenting here, and Barbour and Stejneger, from their study of reptiles, have reached similar conclusions, which accord with the tectonic history of the region, namely, that in late Tertiary, probably Pliocene, time the West Indian Islands as we know them were produced by block-faulting which broke into pieces a far more extensive land area. Dr. W. D. Matthew does not agree with the postulated connections from Cuba to Yucatan, from Jamaica to Honduras, and from Anguilla to South America.[14] The method of distribution of the terrestrial organisms must be left for the consideration of those best versed in such subjects, and I am only warranted in saying that at present there is no known geologic evidence against a late Miocene or early Pliocene connection from Anguilla to South America or from western Cuba and Jamaica to Central America.

Following this geologically late episode of cataclysmic faulting, it appears that in some areas there was minor submergence of the margins of some of the West Indian Islands and parts of Central America—for instance, Panama and Costa Rica.

According to Hill, the volcanoes of the Windward Islands date back at least to the Eocene. He says:

> "After the Miocene, vulcanism became quiescent in the Great Antilles and the Coastal Plain of Texas, but has continued to the present in the four great foci of present activity—southern Mexico, the northern Andes, Central America, and the Windward Islands. In the last two regions mentioned, the greater masses of the present volcanic heights were piled up before the Pliocene, and the present craters are merely secondary and expiring phenomena."

The last important shift in position of strand-line along the Atlantic coast of the United States and around the shore of the Gulf of Mexico and the Caribbean Sea has been by submergence of land areas, but subsequent to this there has been local emergence, often accompanied by minor tilting or warping.

Except vulcanism, the following table presents a succinct summary of the major events considered in the foregoing remarks. My primary intention has been to characterize biologically and to correlate the marine formations of the Canal Zone and the geologically related areas in Central America and the West Indies, and to lay particular stress on the succes-

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[14] Miller says in a letter to me: "Matthew's argument seems to me to have two very weak spots in it: He minimizes the variety of structure shown by the W. I. rodents, and he banks altogether too heavily on what we don't know—that is, on the apparent absence of ungulates and other things that ought to be present in a continental fauna. When it is remembered that all but three of these ten genera of rodents and the insectivore *Nesophontes* were unknown five years ago, we ought to be very shy of predicting what the next digging will not turn up. But it seems to me that what you have quoted of mine contains about all the comment I need to make in print.—G. S. M., Jr."

sive periods of emergence and submergence of the land and the crustal deformation, folding and faulting, concomitant with changes of that kind. Comparison of the table showing the correlation of the Tertiary formations of Panama with the tabular summary will reveal that the story told by the two tables is essentially identical, the erosion intervals and the marine formations in the correlation table representing respectively the periods of emergence and the periods of submergence in the tabular summary.

TABULAR SUMMARY OF SOME OF THE IMPORTANT EVENTS IN THE GEOLOGIC HISTORY OF THE WEST INDIES AND CENTRAL AMERICA

Epoch		Events
Recent		Submergence of land areas, probably resulting from deglaciation, except local differential crustal movements, in places producing uplift.
Pleistocene		Emergence of large areas, probably due to withdrawal of water to form the continental ice-sheets; also oscillation of land areas by differential crustal movement.
Pliocene		Local moderate submergence, period of cataclysmic faulting breaking up a large land area and forming the Antilles nearly as they are at present. Probably a narrow interoceanic connection that admitted an Atlantic fauna into the present site of the Gulf of California.
Miocene	Upper	Extensive emergence of the land joining North and South America through Central America; Greater Antilles joined to each other, and possibly to Central America, by bridges from Jamaica to Honduras and from western Cuba to Yucatan, and to South America along the Caribbean arc. All these supposed connections not necessarily contemporaneous.
	Middle	Extensive marginal submergence in some of the West Indies and on the Atlantic side of Central America. No known interoceanic connections.
	Lower	Extensive submergence in the West Indies and around the continental margins; narrow, areally limited interoceanic connections; land emerging in Central America.
Oligocene	Upper	Extensive submergence with interoceanic connections.
	Middle	Maximum areal submergence with extensive interoceanic connections.
	Lower	Extensive submergence in Central America and the southeastern United States; local emergence in the West Indies.
		Extensive diastrophism and mountain-making by folding.

Epoch		Events
Eocene	Upper	Extensive submergence with interoceanic connections.
	Middle	Apparently interoceanic connection across Central America.
	Lower	Emergence of the Greater Antilles and Central America. No known interoceanic connection.
Cretaceous [3]	Upper	Extensive submergence, but without interoceanic connection.
	Lower	Submergence in southern Mexico and Central America, especially in late Comanche time. Probable emergence in the Greater Antilles. No interoceanic connection.
Jurassic	Upper	Submergence in western Cuba, eastern Mexico, and west Texas, without interoceanic connection, except possibly in late Upper Jurassic time.
	Middle	Submergence in southern Mexico (Oaxaca and Guerrero), with possible interoceanic connection.
	Lower	Submergence in southeastern Mexico (Puebla, Vera Cruz, and Hidalgo, possibly also in Guerrero), with possible interoceanic connection. Non-marine plant-bearing beds in same region and also in Oaxaca. Possibly the latter may be of same age as the supposed Rhætic plant-bearing beds of Honduras and Nicaragua.
Triassic	Upper (Rhætic)	Plant-bearing beds in Honduras and Nicaragua, above mentioned, bespeak land conditions in latest Triassic or earliest Jurassic.
	Upper (Karnic)	Submergence in central Mexico (Zacatecas), with probable interoceanic connection.
	Middle	Probable land conditions throughout Mexico and Central America.
	Lower	Probable land conditions throughout Mexico and Central America.
Late Paleozoic		Formation of the major tectonic axes of Central America and the initial east and west axes of the Greater Antilles.

[3] Mesozoic history of Central America, Mexico, and the West Indies, by T. W. Stanton.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

PALEOGEOGRAPHIC SIGNIFICANCE OF THE CENOZOIC FLORAS OF EQUATORIAL AMERICA AND THE ADJACENT REGIONS[1]

BY EDWARD W. BERRY

(Read before the Paleontological Society December 31, 1917)

CONTENTS

INTRODUCTION

In order not to occupy too much time or confuse my auditors with details, it has seemed best to give a brief summary of the known fossil floras bearing on the problem of intercontinental land connections between North and South America, followed by the conclusions which it has seemed might be legitimately drawn from their evidence.

This evidence is not presented in detail, since it has been given at length in publications recently printed or now in press.[2]

[1] Manuscript received by the Secretary of the Society August 22, 1918.

[2] E. W. Berry: The physical conditions and age indicated by the flora of the Alum Bluff formation. U. S. Geol. Survey Prof. Paper 98 E, 1916.

———: The Lower Eocene floras of southeastern North America. Idem, 91, 1916.

———: The Pliocene citronelle formation of the Gulf Coastal Plain and its flora. Idem, 98 L, 1916.

———: The Catahoula sandstone and its flora. Idem, 98 M, 1916.

———: The Upper Cretaceous floras of the eastern Gulf region. Idem (in press).

———: The Midde and Upper Eocene floras of southeastern North America. Idem (in press).

Upper Cretaceous

The flora which commenced to radiate from Arctogæa in the Cenomanian, and which during the Turonian and Emscherian covered most of North America and Europe, and presumably Asia, penetrated as far as southern South America before the close of the Upper Cretaceous, and at least 26 typical species have been recorded from Argentina.[3] This would seem to indicate that there was some land connection between North and South America throughout the greater part of the Cretaceous, during which time the prevailing direction of migration was from north to south.

Midway Eocene Flora of North America

The small Midway Eocene flora recorded from the Gulf Coastal Plain contains five species belonging to the genera Pourouma, Cecropia?, Asimina, Dolichites, and Terminalia which I have regarded as having been derived from tropical America and as lacking direct ancestors in the Upper Cretaceous of North America.

Wilcox Eocene Flora of North America

In General

This very extensive and well preserved flora comprises to date 345 described species, distributed in 136 genera. There are in common with the almost unknown Tertiary floras of South America 2 species in 2 genera. Those that I consider as having originated in Arctogæa number 179 species in 57 genera. Those whose place of origin is unknown number 65 species in 29 genera. Those that appear to have originated in the American tropics number 101 species in 50 genera.

I do not consider the relationship of the existing flora of the Antilles with that of South America to be as intimate as was the relationship of the Lower Eocene flora of southeastern North America with that of South America. This statement is not true of Central America, where the present lowland flora is a direct continuation of that of South America, while the upland flora is a mixture of survivals from the southward migration of North American types in the Miocene mixed with later immigrants from both the north and the south.

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[2] E. W. Berry: The fossil flora of the Panama Canal Zone. U. S. Natl. Mus., Bull. 103, 1918, pp. 15-44, pls. 12-18.

———: The Tertiary flora of Peru. Proc. U. S. Natl. Mus. (in press).

[3] F. Kurtz: Revista Museo La Plata, vol. 10 (1889), 1902, pp. 43-60.

CLAIBORNE (AUVERSIAN) EOCENE FLORA OF SOUTHEASTERN NORTH AMERICA

The Claiborne flora as at present known comprises 78 species in 59 genera. Of this number 7 genera, with 8 species, are considered as new arrivals from tropical America.

JACKSON (PRIABONIAN) FLORA OF SOUTHEASTERN NORTH AMERICA

The known Jackson flora comprises 79 species in 60 genera. Of this number 6 genera, with 6 species, are regarded as new arrivals from tropical America. These are species of Phœnicites, Myristica, Burserites, Dombeyoxylon, Rhizophora, and Calocarpum. In addition to these, *Palmoxylon lacunosum* (Unger) Felix of the Jackson is probably common to the lower Oligocene (Sannoisian) of the Island of Antigua.

Catahoula and Vicksburg (Oligocene) Floras of North America

The known flora from these formations is a small one, numbering but 24 described species in 15 genera. The only new genus derived from tropical America is the genus Embothrites. Two species of palms, however, are common to the lower Oligocene of the Island of Antigua, another is very close to an Antigua and Panama form, and a third occurs in southern Mexico. There is in addition an undescribed petrified wood in the Vicksburg that is common to Antigua.

Tertiary Floras of South America

The origin of such South American Eocene floras as are known at present may well have been from Arctogæa; but if this was the case, as seems probable, their ancestors reached South America during the Cretaceous, since they are found at a number of widely scattered localities in rocks of earlier Tertiary age, namely, at Coronel, Chile;[4] Santa Ana and Caucathale, in Colombia;[5] Tablayacu and Loja, in Ecuador,[6] and near Tumbez, in Peru[7]. Moreover, the evergreen beeches (Nothofagus) which are found in the lands bordering the present Straits of Magellan[8] appear to be of northern, probably of Asiatic, origin.

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[4] H. Engelhardt: Abh. Senck. Naturf. Gesell., vol. 16, hft. 4, 1891, pp. 629-692, pls. 1-14. Abh. Sitz. Naturw. Gesell., Isis in Dresden, 1905, pp. 69-82, pl. 1.

[5] H. Engelhardt: Abh. Senck. Naturf. Gesell., vol. 19, 1895, pp. 1-47, pls. 1-9.

[6] Idem.

[7] Berry: Op. cit.

[8] C. von Ettingshausen: Sitz. k. Akad. Wiss. Wien, vol. 100, 1891, pp. 114-137, pls. 1, 2.
A. Gilkinet: Resultats voyage du S. Y. Belgica en 1897-1899, 1900.
A. Dusen: Svenska Exped. till Magellanslanderna, vol. 1, 1899, pp. 87-107, pls. 8-13.

The exact ages of these various South American Tertiary floras has never been accurately determined. De Lapparent regarded the first as Eocene, probably Sparnacian. Dusén, following Wilckens, regarded them as Oligocene. It is extremely unlikely that they all are of the same age. Those from Colombia, Ecuador, and Peru I am inclined to regard as the same age as the flora from the Isthmus of Panama,[9] which appears to represent various stages of the Oligocene plus the Aquitanian and Burdigalian, and these find their counterparts in the floras of the Catahoula, Vicksburg, and Alum Bluff formations of the United States and in the petrified woods of Antigua and others of the Antilles.

Part of the Chilean and Patagonian floras appear to be older than these, for they have a few but striking elements in common with those of the lower Eocene of the Mississippi embayment region. Later Tertiary floras from South America not previously mentioned include the Pliocene flora of Bolivia, amounting to 85 species and strictly endemic in character,[10] and a Pliocene flora from the province of Bahia, Brazil, comprising about 70 species, some of which are of North American ancestry.[11]

Summary

The following somewhat categorical conclusions are indicated by a detailed study of the foregoing floras:

1. There appears to have been free intercommunication between North and South America during the Upper Cretaceous, with the invasion of the northern (Holarctic) flora into all parts of South America and probably to Antarctica.

2. Continued land connection between North and South America during the basal and lower Eocene, which, combined with the ameliorating climate of southeastern North America, resulted in the introduction of many new types in that region which were derived from the south.

3. During the middle and upper Eocene, as well as during the Oligocene, there was a continued influx of a few tropical American types into our Southern States, but these were not in sufficient force to demand a land connection between the two regions, nor can it be certain that these types came from South America and not from the intermediate region of Central America and the Antilles.

4. During the Oligocene there appears to have been a rather free interchange of plant types between Panama and the Antilles, best illustrated

[9] Berry: Op. cit.

[10] E. W. Berry: Proc. U. S. Natl. Mus., vol. 54, 1917, pp. 103-164, pls. 15-18.

[11] F. Krasser: Sitz. k. Akad. Wiss. Wien., vol. 112, abh. 1, 1903, pp. 852-860. Ed. Bonnet: Bull. Mus. d'hist. Nat., année 1905, pp. 510-512.

by the extensive flora of petrified woods found on Antigua, which has several forms common to Central America and the southeastern United States.

5. In formations correlated with the Aquitanian and Burdigalian of the European section, but generally considered as upper Oligocene by American geologists, the tropical types of plants become fewer on the North American mainland and are largely replaced by temperate forms.

6. The land emergence of the Miocene appears to have developed land connections in Central America and the Antilles reflected in the floras by a general spreading southward of the temperate flora of North America. This emergence resulted in the connection of the Windward Islands with South America, Cuba with Yucatan, and the Jamaica, Haiti, and Porto Rico axis of elevation with Honduras. To this period may be attributed the original colonization of the many North American types that still persist in the Antilles and Central America. The invasion of the latter regions, and that beyond in South America, by the oaks (Quercus), walnuts (Juglans), and many other Holarctic types probably occurred at this time, since some of them are found in the Pliocene of Brazil. The radiation of the agaves may also be more appropriately dated from the Miocene rather than from the Pleistocene, as is done by Trelease,[12] since while there was considerable elevation during the Pleistocene the major tectonic lines were established during the Pliocene by block faulting, as Vaughan has shown, and the failure of Agave to penetrate to any considerable extent into South America was due to the impenetrability of the tropical rain forest and not to geographical barriers.

7. North and South America were connected during the Pleistocene and there was considerable elevation in the Antillean region, resulting in a northward spread from South America of various elements from the rain forests of the Amazon and Orinoco basins, one or two of which occur in the late Pleistocene of southern Florida. Actual land connections among the Antilles or with Florida are not considered probable.

Note

There are a number of reasons why the arguments against a land bridge between North and South America based on the evidence of vertebrate paleontology can not be regarded as conclusive. It is opposed by the evidence derived from the study of the distribution of other animal types, as has been already pointed out by several students.

First, as regards actual changes in level. The general thesis of the

[12] William Trelease: Mem. Natl. Acad. Sci., vol. 11, 1913.

permanency of ocean basins, as developed by Matthew in "Climate and evolution,"[13] seems unquestionably sound in the present state of our knowledge of isostatic compensation. Whether the latter was always as complete as it seems to be at present may well be doubted—certainly we know of remarkably great epeirogenic changes, and, furthermore, a rather good case can be made out for the theorem advanced by Walther and others, that the deep seas are post-Mesozoic in age. Be this as it may and while its acceptance does not directly oppose Matthew's contention, the present continental scarps can not be regarded in all cases as the metes and bounds of the continents in past times, and a very strong case can be made out for Suess's sunken block theory in a large number of areas, *and especially in the Caribbean region.*

It seems to me, as I review the various lines of evidence, that the long region of weakness extending from Graham Land to the Antilles may well indicate that the Antilles were once a part of South America, and that the latter continent was connected with Antarctica. I have recently shown that the change of elevation of the great central plateau of Bolivia and the eastern Andes in that region has amounted to a minimum of 2½ miles since the Pliocene,[14] and the weight of this argument is not disposed of by calling these changes orogenic instead of epeirogenic. I am therefore the more inclined to believe that comparable changes of level have taken place in the Caribbean region during the Tertiary.

In all discussions of paleogeography based on the distribution of the mammals it should be constantly borne in mind that the facts, in so far as they contribute toward an understanding of the relations between North and South America, are derived almost entirely from the region of the Great Plains and Rocky Mountains in North America and from Argentina in South America—regions which were separated, at least during the Eocene and the Oligocene, as they are today, by the greatest extent of tropical rain forest on the globe. The fact that the edge of this equatorial American rain forest appears to have covered the southern shores of the United States during the first half of the Tertiary renders it obvious why the Artiodactyla and Perissodactyla of our western plains were not exchanged for the typotheres and litopterns of Patagonia.

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[13] W. D. Matthew: Annals N. Y. Acad. Sci., vol. 24, 1915, pp. 171-318.
[14] E. W. Berry: Proc. U. S. Natl. Mus., op. cit.

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AGE OF CERTAIN PLANT-BEARING BEDS AND ASSOCIATED MARINE FORMATIONS IN SOUTH AMERICA[1]

BY EDWARD W. BERRY

(*Read before the Paleontological Society December 31, 1917*)

CONTENTS

INTRODUCTION

Tertiary sediments are found at scattered localities throughout the continent of South America, and the Argentina Tertiaries in particular have been extensively exploited in connection with the study of the varied vertebrate fossils which they contain. Marine Tertiary deposits are found in the latter region as well as around the margin of the Brazilian plateau; they are widely distributed along the west coast, and in the Andean region they are scattered from Colombia and Venezuela to Tierra del Fuego and beyond. Our knowledge of all of these is very fragmentary and is limited for the most part to incidental descriptions in connection with the study of the contained floras or faunas rather than on detailed areal and stratigraphic work.

In the present brief contribution the discussion is centered on the pre-Pliocene Tertiary of the Andean region and of the west coast, since the data at hand seem sufficient for tentative correlations and it is the beds in this part of the continent that may be expected eventually to unravel the geological history of the Andean chains. In the Andean region itself

[1] Manuscript received by the Secretary of the Society August 22, 1918.

FIGURE 1.—*Map of South America*

Showing distribution of lower Miocene plant beds: 1, Canal Zone; 2, Santa Ana, Rio Magdalena Valley, Colombia; 3, near Buga, Rio Cauca Valley; Colombia; 4, Tablayacu, Rio Jubones basin, Ecuador; 5, Loja basin, Ecuador; 6, near Tumbez, Peru; 7, Coronel, Chile; 8, Navidad beds, Chile; 9, Patagonian beds, Argentina.

certain localities are not mentioned, either because of the absence of fossil plants or for the reason that no definite opinion seemed permissible. The principal localities that are referred to are shown on the accompanying sketch map (figure 1) and will be discussed in regular order.

Canal Zone

The described section in the Canal Zone (locality number 1) is of the greatest importance in this connection, for while it is not a part of the Andean system, the Canal Zone, because of its nearness to South America and the rather definite correlation of its Tertiary formations, offers a convenient standard for comparison. Moreover, the geological history of the Isthmian region has a direct bearing on the facies of the marine faunas of the west coast and the history of the terrestrial floras that have entered South America from North America during those times that the Isthmus was above the sea. The section need not be quoted in the present connection, since the formations have recently been described by MacDonald,[2] and their correlation with the Tertiaries of our Southern States, the Antilles, and Europe has been given in an important paper by Vaughan.[3]

The geological history of the Isthmus arrived at by Vaughan indicates that the region was emerged, and that there was no interoceanic connection across it during the whole of the Cretaceous and the earlier half of the Eocene, and that there was free communication between the two oceans during the Upper Eocene, Oligocene, and Lower Miocene. This has an important bearing on the history of the floras and faunas of the region to the southward, as I have already mentioned, and it will develop on subsequent pages that this history corresponds with the history of the opposite end of South America, and also accounts for the Mediterranean elements found in the Tertiary marine faunas of Peru and Chile.

Colombia

Fossil plants have been described from two localities in Colombia. These are Santa Ana (locality number 2), along the western margin of the Rio Magdalena Valley, and near Buga (locality number 3), in the Rio Cauca Valley. The first is between the eastern and central and the second between the central and western Andean chains. At both locali-

[2] D. F. MacDonald: U. S. Bureau of Mines, Bull. 86, 1915; U. S. Natl. Mus. Bull. 103 (in press).

[3] T. W. Vaughan: U. S. Natl. Mus. Bull. 103 (in press).

ties the fossil plants occur in tuffs,[4] and there is no evidence of contemporaneous or subsequent marine deposits in this general region, although it must be constantly borne in mind that the area has been very imperfectly explored. The flora found near Buga is very limited in extent, and while it is probably the same or very nearly the same age as that found in the Rio Magdalena Valley, this can not be demonstrated. The flora of Rio Magdalena Valley comprises 35 species, well distributed among the natural orders. It is clearly a mesophytic tropical flora and it contains numerous elements that are strictly South American in existing floras. Among these are the genera Stenospermatium, Goeppertia, Acrodiclidium, Condaminea, Vochysia, Trigonia, etcetera. Nine of the Santa Ana species have an outside distribution. Seven of these have been found in Peru, two in Ecuador, and two in Chile. These afford a basis for tentative correlation which will be referred to in a subsequent paragraph, since the basis for all of the proposed correlations rests on various collateral lines of evidence rather than on direct individual comparisons.

Stille[5] has described coarse valley filling in the Rio Magdalena Valley which he calls the Honda beds. These may possibly be of the same age as the plant-bearing tuffs, but they are probably much younger and may be considered to represent upper Miocene or Pleistocene continental sediments or possibly both.

Ecuador

Fossil plants are known from two principal localities in Ecuador. These are Tablayacu (locality number 4), in the Rio Jubones basin, and several localities in the Loja basin (locality number 5). Only three species are recorded from the former, but one of these is also found in the Loja basin, and it therefore seems probable that the two deposits are of the same age. The occurrence of lignites and associated leaf impressions in the Loja basin has been known for a generation or longer.[6] Engelhardt[7] has described 40 species of fossil plants from this locality, but the age of the beds has never been fixed beyond that they were Tertiary. One of the Loja plants occurs in the Colombia deposits, another in the Caimito formation of the Canal Zone, three are found in Chile, and one in Peru. The flora, judged by modern standards, is distinctly South American in its facies, with species of Arthante, Hieronymia, Cam-

[4] H. Engelhardt: Abh. Senck. Naturf. Gesell., Band 19, 1895.

[5] H. Stille: Geologische Studien im Gebiete des Rio Magdalena. von Koenen Festschrift, 1907, pp. 277-358.

[6] T. Wolf and G. Rath: Zeits. Deutsch. Geol. Gesell., Bd. 28, 1876, pp. 391-393.

[7] H. Engelhardt: Abh. Senck. Naturf. Gesell., Bd. 19, 1895.

phoromœa, Luhea, Banisteria, Tapiria, Vochysia, and other South American types, and denotes a mesophytic tropical environment.

Peru

From near Tumbez (locality number 6), on the coast of Peru, I have recently described a small flora of 14 species,[8] of which several are only tentatively identified because of the fragmentary nature of the material. Seven of these species are common to the Tertiary of Colombia, one is found in the Culebra, Gatun, and Caimito formations of the Canal Zone, one in the Loja basin of Ecuador, one in Chile, and another is close to if not identical with a Chilean form. This flora denotes very different climatic conditions from those that prevail at the present time in this semi-desert coastal region.

The plant localities in Colombia and Ecuador represent continental deposits and lack marine faunas. In the case of Tumbez, however, we are dealing with lagoonal deposits intercalated in a marine fossiliferous series, so that the evidence of the flora can be checked by a certain amount of faunal evidence. The general section of the Tertiary of the coastal region of Peru is segregated by Grzybowski[9] into the following units, to which he assigns the ages as given below:

Paita stage	Pliocene
Talara stage	Upper Miocene
Zorritos stage	Miocene
Heath stage	Lower Miocene
Ovibio stage	Oligocene

The fossil plants come from the Heath stage. The small fauna found in the associated beds of this stage comprise 19 species, representing the genera Arca, Turritella, Pyrula, Puncturella, Ostrea, Venus, Cytherea, Cardium, Lutraria, Dosinia, Leda, and Lucina. *Venus münsteri* and *Lutraria vetula* are common to the Navidad beds of Chile, *Cytherea planivieta* occurs in the Bowden marl of Jamaica, and *Turritella altilirata* in the Gatun formation of the Canal Zone. The genera Lutraria, Ostrea, and Cardium have closely related species in the Navidad beds of Chile, and Dosinia is represented by a closely related species in the Miocene of the Island of Trinidad. The Bowden marl has been shown to be of Burdigalian age by Woodring, while the Gatun formation, according to Douvillé and Vaughan, represents both Burdigalian and Helvetian. The

[8] E. W. Berry: U. S. National Museum, Proc., vol. 55, 1919, pp. 279-294, pls. 14-17.

[9] J. Grzybowski: Die Tertiärablagerungen des nördlichen Peru und ihre Molluskenfauna. Neues Jahrb. Beil., Bd. 12, 1899, pp. 610-664, pls. 15-20.

fossil plants associated with the foregoing mollusca in Peru appear to be Aquitanian or Burdigalian in age, and a consideration of both classes of evidence leads to the conclusion that this flora and the associated fauna of the Heath stage are of Burdigalian age.

Chile

There are at least two Tertiary fossiliferous horizons in Chile. These are the Coquimbo beds and the Navidad beds. The former do not concern the present discussion, particularly since they are probably of Pliocene age and correspond to the Paita stage of Peru. The second, or Navidad, beds (localities 7 and 8) have an important bearing on the present discussion. They comprise prevailingly arenaceous deposits carrying locally an abundant marine fauna, and toward the base, according to Steinmann, coal beds and an associated terrestrial flora. While their areal distribution and stratigraphic or structural relations have never been described, they have been recognized at a number of scattered localities and there has been a tendency, exemplified by Möricke, to carry the name Navidad to more or less uncertain correlatives in other parts of South America. Along the west coast of Chile, however, at Navidad, Matanzas, Lebu, Coronel, Lota, Puchoco, Island of Chiloé, and elsewhere, they have been definitely recognized and they may extend as far southward as the Straits of Magellan.

The Navidad fauna, which is extensive, has been described principally by Philippi[10] and Möricke.[11] It shows closer relationships with the Tertiary faunas of Europe than with the corresponding faunas of Australia and New Zealand, although it contains some elements common to the latter. Engelhardt[12] has described an extensive flora from the coal-bearing sandstones in the Navidad beds near Coronel. This flora consists of 94 species, well distributed among the natural orders and indicative of tropical humid conditions. It is of great interest, in that it contains a considerable element derived from the north and also found in the Eocene of southeastern North America. This element includes the genera Zamia, Anona, Myristica, and representatives of the families Papilionaceæ, Bombacaceæ, Dilleniaceæ, Lauraceæ, Myrtaceæ, Boraginaceæ, and Rubiaceæ. Compared with the known fossil floras from other parts of South Amer-

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[10] R. A. Philippi: Die tertiären und quartären Versteinerungen Chiles. Leipzig, 1887.

[11] W. Möricke: Versteinerungen der Tertiärformation von Chile. Neues Jahrb. Beil., Bd. 10, 1896, pp. 548-612, pls. 11-13.

[12] H. Engelhardt: Ueber Tertiärpflanzen von Chile. Abh. Senck. Naturf. Gesell., Bd. 16, hft. 4, 1891, pp. 629-692, pls. 1-14. Bemerkungen zu chilenischen Tertiärpflanzen. Abh. naturw. Gesell., Isis in Dresden, 1905, pp. 69-82, pl. 1.

ica, the Navidad flora contains 3 species in common with that found in the Loja basin of Ecuador, 2 species in common with that found in Colombia, and 2 species in common with that described recently from Peru. When compared, on the other hand, with the geographically much less remote flora found in the Magellanian beds along the straits of that name and on Tierra del Fuego, it is found to have nothing in common with the latter except a single species of Flabellaria, about which Dusén expresses the opinion that it could not have come from the Magellanian beds, and in this Dusén appears to be perfectly justified. It appears that the Navidad flora is younger than the floras known from farther south.

Before discussing the age of the Navidad beds, I wish to refer to the so-called Patagonian beds of southern Argentina, the marine fauna from which has been admirably described by Ortmann.[13] This fauna has been satisfactorily shown to be of lower Miocene age, and while the Australian and New Zealand element is more pronounced than in the Navidad beds, nevertheless the Patagonian has, out of a total fauna of 151 species, 34 that are identical with and 15 additional that are closely allied with Navidad species. Ortmann quite rightly concludes that the Patagonian is synchronous with at least a part of the series referred to the Navidad.

In conformity with the conclusions of invertebrate paleontology as expressed by Steinmann, Möricke, Ortmann, and others, and from a consideration of the flora found in these beds, I would confirm the lower Miocene age of a part at least of what goes under the name of Navidad beds and I would consider them as representing the Burdigalian stage and possibly the older Aquitanian stage as well, since transgression was continuous in Europe from the one to the other as it was also in the Canal Zone. The presence of some of the mollusca of the Navidad beds in the Magellanian Oligocene may indicate that a part of the former is still older than Aquitanian, but this I greatly doubt, since the facts can be explained by intermigrations of the forms better than by postulating contemporaneity. The facies of the Navidad flora appears to be slightly older than the previously mentioned fossil floras from Colombia, Ecuador, and Peru, and it may well fall within the Aquitanian, but it is surely not so old as Eocene, as Steinmann and De Lapparent suggest, nor is it so old as the Fagus flora of the Straits of Magellan and Tierra del Fuego, which I have considered as Lower Oligocene in age.

Windhausen[14] has recently described the hitherto unknown (wrongly

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[13] A. E. Ortmann: Tertiary Invertebrates. Princeton Exped. to Patagonia, vol. 4, 1901-1906, pp. 45-332, pls. 11-39.

[14] A. Windhausen: The problem of the Cretaceous-Tertiary boundary in South America and the stratigraphic position of the San Jorge formation in Patagonia. Am. Jour. Sci. (iv), vol. 45, 1918, pp. 1-53.

correlated) transgression of what he calls the San Jorge formation, which in the early Eocene flooded the east coast of southern Argentina and penetrated northwesterly up the Roca Valley. I mention this admirable contribution in the present connection, since it has a bearing on the age and antecedent history of the Magellanian beds.

At Punta Arenas and elsewhere along the Straits of Magellan and at various localities in Tierra del Fuego a series of sandy lignitic beds have been described by Ortmann, Hatcher, Nordenskjold, and others, which are of the greatest interest to paleobotanists because of the remarkable flora contained near their base. The section, somewhat abbreviated, is as follows:

1. Sands, lignitic sandstone, and conglomerates = horizon V of Hatcher = Patagonian formation of Ortmann = Burdigalian.
2. Sandstones with lignite beds and fossil plants = horizon IV of Hatcher = Upper lignites or Punta Arenas coal = Miocene Araucaria beds of Dusén = Acquitanian.
3. Sandstone with oyster beds = horizon III of Hatcher = Oligocene.
4. Sandstones with fossiliferous calcareous lenses = Oligocene.
5. Fossiliferous beds = horizon II of Hatcher = Oligocene.
6. Sand and sandstone with fossiliferous calcareous concretions and fossil plants = horizon I of Hatcher = Oligocene Fagus zone of Dusén = Oligocene.
7. Lignitic shales = Lower lignites of Hatcher = Oligocene (?).

This section presents the record of a minor oscillation of the strandline with continental deposits passing into lagoonal, and these into littoral and shallow-water marine, and then gradually shallowing and perhaps becoming emergent during the Aquitanian, followed by a marked transgression in the Burdigalian. At present our chief interest centers in the Fagus zone and its flora. This flora, as described by Dusén,[15] consists of 29 species, of which the Flabellaria, previously mentioned as doubtful, is the only one that occurs in the Tertiary floras already enumerated from South America. The particular facies of this flora is furnished by the abundance of Fagaceæ. This family is represented by two species of Fagus and by 13 species or varieties of Nothofagus. This flora is certainly older than those already mentioned and it is as certainly Tertiary in age. It unquestionably had its beginnings in the Northern Hemisphere and has also been found to be represented at somewhat similar horizons in Australia, New Zealand, and Antarctica. That it did not migrate into Patagonia from North America appears to be probable from the absence of any definite ancestral assemblage in the abundantly fos-

[15] P. Dusén: Ueber die tertiäre Flora der Magellansländer. Svenska Exped. till Magellansländerna, Band 1, 1899, pp. 87-107, pls. 8-13.

siliferous Upper Cretaceous or Eocene of the latter continent from which it seems probable that it could have been derived. Nor are any traces of it found at more northern localities in South America. The explanation seems to be that it reached southern South America from the opposite direction, namely, Antarctica.

A very interesting Tertiary flora has been recently described[16] from the border of the Antarctic continent on Seymour Island, off the east coast of Graham Land. This flora contains a large element of subtropical types like those found today in southern Brazil, and another large element of forms suggestive of the existing temperate flora of southern Chile and Patagonia, and including species of Fagus and Nothofagus like those found in Patagonia, Chile, Australia, and New Zealand. Dusén, ignoring the usually mixed climatic character of early Tertiary floras, and the association of tropical and temperate types under favorable conditions of humidity, and basing his conclusions on the broken character of the fossil remains of these temperate types, reaches the conclusion that the temperate and the subtropical elements were contemporaneous, but that the latter were coastal forms under a subtropical climate, while the former grew in the vicinity at elevations which he suggests amounted to 6,500 feet or more, and were brought by streams to the littoral basin of sedimentation. If this is true, it indicates a considerable mountain chain of the Andean type forming the axis of Graham Land at that time as it does at present. The only evidence bearing on the age of the folding, which may really have little bearing on the time of elevation, is the presence at Hope Bay, on Graham Land, of an extensive late Jurassic flora[17] found in continental beds which are involved in this folding. Dusén concludes that this Tertiary Antarctic flora is older than that of the Fagus zone of the Magellanian beds.

Poorly preserved mollusks associated with the plants are considered by Wilckens to represent what he calls the Patagonian molasses, but since the latter is more or less composite, as Windhausen[18] has shown, and includes faunal elements belonging to the lower Eocene San Jorge formation as limited by the latter author, the evidence for the correlation adopted by Andersson[19] can not be said to be conclusive. The presence of Zeuglodon vertebræ, described from this locality by Wiman, should probably be con-

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[16] P. Dusén: Über die Tertiäre Flora der Seymour-Insel. Wiss. Ergeb. Schwed. Südpolar-Exped., Band 3, 1908, 27 pp., 4 pls.

[17] T. G. Halle: The Mesozoic flora of Graham Land. Swedish South Polar Exped., 1901-1903, Band 3, lief 4, 1913, 123 pp., 9 pls.

[18] Op. cit.

[19] J. Gunnar Andersson: On the geology of Graham Land. Bull. Geol. Inst. Upsala, vol. 7, 1906, pp. 19-71, pls. 1-6.

sidered as evidence of Eocene age. I would therefore dissent from Wilcken's conclusions that this plant-bearing sandstone is Upper Oligocene or Lower Miocene in age and would consider this flora as of Middle or Upper Eocene age.

Summary

Summarizing the foregoing brief notes and going beyond them into the Mesozoic in order to indicate land connections that were barriers to marine dispersal and avenues for the migration of terrestrial faunas and floras, it may be noted that South America and Antarctica were connected during the late Jurassic, and that this connection was not interrupted during the long ages of the Lower Cretaceous. At the other end of South America Panama appears to have been emerged throughout the Lower Cretaceous, but there was no direct connection between Antarctica and North America, unless it was over an Antillean land bridge, until near the end of the Lower Cretaceous, at which time a continuous land connection was established which continued with various modifications throughout the Upper Cretaceous.

During the Upper Cretaceous the world-wide Emscherian-Lower Aturian transgression is recorded in the Quiriquina beds of Chile, at various localities in Peru and Patagonia, and in the richly fossiliferous deposits of Graham Land, with their Indo-Pacific ammonite faunas. Although it was perhaps possible for these latter faunas to have invaded the margins of Graham Land from the east, it seems more probable, in view of the similarities of the fauna to that found in the Quiriquina beds of Chile, that the land connection with Antarctica which had persisted since Jurassic time was interrupted during the middle part of the Upper Cretaceous, at which time shallow marine waters permitted the invasion of the region by these ammonite faunas.

Toward the close of the Upper Cretaceous, however, and throughout all of southern and western South America, there is evidence that this Upper Cretaceous submergence was followed by a negative movement of the strand-line and emergence of the land. This occurred during the time interval of the Maestrichtian and Danian stages of the Upper Cretaceous and continued for a much longer time than this throughout most of South America. This late Upper Cretaceous emergence is shown by the absence of any known faunas representing these stages, by the lithologic indications in the higher levels of increasing shallowness of the waters, and by the continental variegated sandstones of this age in Patagonia. At this time, then, Antarctica was connected with Patagonia and the Isthmus of Panama was dry land.

This emergent phase continued throughout nearly the whole of the Eocene, for while there was a local transgression from the East, represented by the San Jorge formation in Patagonia, this was not of sufficient magnitude to connect the waters of the Atlantic and the Pacific. There was thus afforded an opportunity for the flora of North America to invade South America at the beginning and toward the close of the Upper Cretaceous, already indicated by the presence of representatives of the Dakota sandstone flora in Argentina,[20] and similar land connections were available throughout most of Eocene time. Similar opportunities for the interchange of terrestrial life, both animal and vegetable, between South America and Antarctica were also present during these same intervals.

During the Oligocene there is evidence of minor transgressions in Panama; on the Peruvian coast, where the Ovibio stage contains two or three marine forms but is mainly a littoral and continental flysch-like sandstone; in Patagonia, where the Magellanian beds contain oyster beds and a few other shallow-water marine forms between two lignitic horizons. This Oligocene emergence is marked in Chile and Graham Land, and by the continental Deseado formation (Notostylops, Pyrotherium beds) of Patagonia.

Toward the end of Oligocene time or the beginning of Lower Miocene (Aquitanian-Burdigalian stages) we everywhere find evidence of marked submergence. This is shown by the Culebra, Emperador (continental), and Gatun formations of Panama; by the Zorritos and Heath stages of Peru, and by the Navidad beds of southern Chile. The faunas of these west coast beds are remarkable for the Caribbean and Mediterranean elements that they have furnished, thus affording collateral evidence of the free mingling of the waters of the Atlantic and the Pacific where the Isthmus of Panama now stands. Similar evidence of submergence is furnished by the marine Patagonian beds, whose fauna has been described by Ortmann, and possibly by a part of the younger Seymour Island beds of Andersson.

The upper Miocene is, so far as I know, a time of rather widespread emergence and land connections. No marine upper Miocene is known from Panama, Chile, Patagonia (continental Santa Cruz beds), or Antarctica. The Talara stage of Grzybowski in northern Peru is the only exception to this statement, and if it is correctly correlated it represents a very minor movement of the strand.

Following the widespread upper Miocene emergence, there is an equally widespread Pliocene submergence, illustrated by the Toro limestone of

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[20] F. Kurtz: Sobre la existencia de una Dakota-Flóra en la Patagonia austro-occidental. Revista Museo de La Plata, vol. 10, 1899, pp. 43-60.

Panama, the Paita stage of Peru, the Coquimbo and Caldera beds of Chile, the Parana beds of Patagonia, and the Pecten beds of Graham Land. It is also emphasized by the presence of a marine Pliocene fauna at elevations of over 13,000 feet in the eastern Andes of Bolivia.[21] The subsequent history need not be discussed, although this widespread similarity of events continued throughout the coastal region down to the present.

This parallelism in the movements of the strand over so vast an area is so remarkable that I have gathered together such information as is available in the accompanying table. While this is very incomplete, it seems worth presenting in tabular form and it will also serve as a graphic summary, without additional discussion, of the correlations that I have arrived at from a study of these various plant-bearing horizons and associated beds in South America.

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[21] E. W. Berry: U. S. Natl. Mus., Proc., vol. 54, 1918, no. 2229.

		PATAGONIA.	GRAHAM LAND.
Recent.	Em	Emergence.	Emergence.
Late and post-Glacial.	Sub	Submergence.	Submergence.
Glacial.	Em	Emergence.	Emergence.
Pliocene.	Tor-	Parana beds.	Pecten beds.
Upper Miocene.	Em	Emergence (Santa Cruz beds).	Emergence.
Lower Miocene, Burdigalian, and Aquitanian.	Gat p p.	Patagonian beds. Punta Arenas coal (Araucaria).	Possibly a part of the younger Seymour Island beds of Andersson.
Oligocene, Chattian, Stampian, Sannoisian.	Low li gl Eme	Deseado (Notostylops and Pyrotherium beds). Local submergence in the Magellanian beds. Fagus and lower lignite beds.	Emergence.
Eocene.	Tra E Eme	Emergence. Local transgression of San Jorge formation (Roca beds).	Littoral sediments with fossil plants. Emergence.
Upper Cretaceous. Danian and Maestrichtian.	Eme	Emergence with variegated continental sandstones.	Emergence.
Upper Cretaceous. Campanian, Emscherian, Turonian.	Eme	Submergence.	Rich Indo-Pacific Ammonite faunas.
Lower Cretaceous.	Eme	Emergence (local marine beds).[22]	Emergence.

TABULAR SUMMARY

	Panama.	Colombia.	Ecuador.	Peru.	Bolivia.	Chile.	Patagonia.	Graham Land.
Recent.	Emergence.	Emergence.	Emergence.	Emergence.	Emergence.	Emergence.	Emergence.	Emergence.
Late and post-Glacial.	Submergence.	?	?	Submergence ("tablaza" beds).	?	Submergence. Valparaiso stage.	Submergence.	Submergence.
Glacial.	Emergence.	?	?	Emergence.	?	Emergence.	Emergence.	Emergence.
Pliocene.	Toro limestone.	?	?	Paita stage.	Discinisca and plant tuffs of Potosi and Corocoro.	Coquimbo and Caldera beds.	Parana beds.	Pecten beds.
Upper Miocene.	Emergence.	Honda beds?	?	Talara stage.		Emergence.	Emergence (Santa Cruz beds).	Emergence.
Lower Miocene, Burdigalian, and Aquitanian.	Gatun formation, Emperador limestone, Upper Culebra.[21]	Andean plant beds. Santa Ana.	Andean plant beds. Loja coal.	Zorritos and Heath stages. Fossil plants of Tumbez.		Navidad beds. Fossil plants of Coronel and Lota.	Patagonian beds. Punta Arenas coal (Araucaria).	Possibly a part of the younger Seymour Island beds of Andersson.
Oligocene, Chattian, Stampian, Sannoisian.	Lower Culebra, Tonosi limestone, Bohio conglomerate. Emerged?			Ovibio stage, mainly continental sandstones.		Emergence.	Deseado (Notostylops and Pyrotherium beds). Local submergence in the Magellanian beds. Fagus and lower lignite beds.	Emergence.
Eocene.	Transgression in Upper Eocene. Emergence.			Emergence.		Emergence.	Emergence. Local transgression of San Jorge formation (Roca beds).	Littoral sediments with fossil plants. Emergence.
Upper Cretaceous. Danian and Maestrichtian.	Emergence.			Emergence.		Emergence.	Emergence with variegated continental sandstones.	Emergence.
Upper Cretaceous. Campanian, Emscherian, Turonian.	Emergence.			Submergence.[23]		Quiriquina stage.	Submergence.	Rich Indo-Pacific Ammonite faunas.
Lower Cretaceous.	Emergence.			Emergence. Local marine beds[23] (Wealden flora).		Emergence.	Emergence (local marine beds).[22]	Emergence.

[21] More or less contemporaneous.
[22] Halle (1913) has recorded Lower Cretaceous, perhaps Aptian, on the Lago San Martin.
[23] Neumann: Neues Jahrb. Beil., Bd. 24, 1907.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

BEARING OF THE DISTRIBUTION OF THE EXISTING FLORA OF CENTRAL AMERICA AND THE ANTILLES ON FORMER LAND CONNECTIONS *

BY WILLIAM TRELEASE

(*Read before the Paleontological Society December 31, 1917*)

CONTENTS

Break in West Indian Flora between Saint Croix and Saint Thomas

Apart from weeds of various origin and occurrence, the West Indian flora is an intricate blending of plants identical with or closely related to those of South America on the one hand and of North America on the other hand, with a relatively small proportion of true endemism of types. The chain of islands has been held for a "province" of the Tropical American floral region, correlated with the tropical Mexican province of North America and the subequatorial Andine and cisequatorial Savanna provinces of South America and contiguous Central America.

The flora of Trinidad and other islands close to the South American coast is essentially a South American flora except for obvious introductions. The flora of the Bahamas may be said to have contributed characteristic elements to subtropical Florida, rather than to be a temperate North American flora, and it appears to be largely of Cuban derivation.

A number of years since, Baron Eggers[1] showed that a considerable

* Manuscript received by the Secretary of the Society August 22, 1918.
For references, see page 656.

percentage (25) of the species of higher plants, as he understood them, of Saint Thomas and the adjacent Cretaceous Virgin Islands are not found in the Tertiary island Saint Croix, only some 30 miles away, and that only about 11 per cent of the species of Saint Croix occur also in Saint Thomas. As a general fact, it may be stated that those which stop in Saint Croix are endemic or derived from or represented by species of the Lesser Antilles, and of South American affinity or origin, and that those which stop in Saint Thomas, if not endemic, are of North American origin or affinity, with representatives in the Greater Antilles. Here North America does not mean or include, so far as cases are significant, the subtropical or even warm part of the United States, but it is to be understood as referring to the Mexican and Yucatecan floral zones.

It has been my privilege to become so familiar with the world representation of a few groups of plants that I may venture to speak of their geographic distribution with some confidence. What I know of them in this respect may be stated as follows:

Quercus suggests lack of Land Connection with North America

The oaks (*Quercus*)[2] constitute an ancient genus, dating from the Cretaceous, scarcely changed since the Pleistocene, and apparently going well into the Pliocene essentially in their present specific forms. The genus is world-wide in its distribution in the Northern Hemisphere now. In America it is essentially North American. Only a few oaks now occur in South America—in the Andes of Colombia. These appear to me closely related to certain Costa Rican species, and thus far support the recognition of a subequatorial Andine province comparable with the cisequatorial and Central American provinces with which the West Indies are correlated in their flora. If their remains have been identified correctly, a few oaks occurred in Pliocene time in what is now arid equatorial Brazil. I have not seen specimens or illustrations of these, but should have difficulty in comparing them, as described, with existing species or with other Pliocene species of the genus.

Only one oak, scarcely differentiable from the live-oak of our Gulf States and its equivalent of the Mexican and Central American coastwise region, occurs in western Cuba. This can hardly be regarded otherwise than as an introduction from the north. The live-oaks of this type appear to represent a rather early stock among modern oaks. In the absence of paleontological evidence, it may be unsafe to attempt to say when the live-oak entered Cuba, but evidence is more necessary for the support of a hypothesis that this was in Tertiary times than for my personal view

that it was later than the Pleistocene. Some of Catesby's oak localities have been misunderstood because of the inclusion of both continental and insular species in his illustrations; but it may be said with confidence that *Quercus* is unrepresented in the West Indian flora except by this single Cuban form. So far as fossil and existing oaks are known, they offer no facts pointing to a connection of the West Indies with North America in recent time. The absence of such facts may be taken as indicating that no such connection has existed.

Nolineæ and Yucceæ indicate Absence of continental Land Connection

Among the xerophytic lily-like plants I may claim sufficient familiarity with the liliaceous groups Nolineæ and Yucceæ and the Amaryllidaceous group Agaveæ to discuss their bearing on this question. Unlike the oaks, these are all exclusively American; and they appear to be of late Tertiary origin, though very little is known of them except as more recent plants.

The Nolineæ[3] are not known to occur away from continental North America. They range from southern Colorado southwestward through Baja California and southeastward over the tableland, one of their four genera (*Beaucarnea*) dropping into the *tierra caliente* of Vera Cruz, Yucatan, and Chiapas in Mexico and the lower mountains of Guatemala. An eastern extension of another (*Nolina*) is known for South Carolina, Georgia, and Florida through evident derivatives of its Texan representatives, though it is absent from the intervening Gulf States. This group of the tableland, therefore, throws no light on the question, unless, negatively, the absence of its representatives from the West Indies indicates that Cuba has been connected with neither Yucatan nor Florida since the appearance of *Beaucarnea* in the former and of *Nolina* in the latter.

The Yucceæ, also absent from South America, appear to be more distinctly boreal plants than the Nolineæ are. They range southward from the great bend of the Missouri River to the Atlantic and Pacific coasts, and, over the tableland, to Puebla and Jalisco. In the West Indies only one representative of this group is known, the common Spanish dagger of our Gulf States. This is fairly wide-spread through the islands, but perhaps never free from question as to spontaneity, because it is planted everywhere.[4] In its genus, this species (*Yucca aloifolia*) is distinct in lacking a papery core to its fleshy fruit and in having acquired or retained a power of self-pollination which its congeners do not possess.

If these differences are significant, and if the Spanish dagger is native to the islands, it may be that this species acquired its distinctive charac-

ters either in the Antilles or in the Gulf region of our Atlantic States or of Mexico, and passed from the one into the other. Since this is the only yucca with pulpy fruit in our Atlantic region, while baccate species range through Mexico as far as the genus reaches, the probability is that its prototype originated on the mainland to the south, and that in its present form it recrossed into its now rather limited areas to the north and west.

Neither of these suppositions need be regarded as indicating a land connection between the West Indies and North or Central America, for a plant with edible fruit may have passed easily greater barriers than those separating the West Indies from North America. In any event, the Yucceæ offer no other indication of such a land connection, and they give no suggestion of a connection between the West Indies and South America.

Phoradendron and Furcræa suggest Land Connection with North and South America

The distinctively American mistletoe genus *Phoradendron* possesses a vastly greater American range than either of the groups so far considered. Species are found from ocean to ocean, and from the extreme northwestern limits of the United States to the mouth of the river La Plata, in South America. Unlike the other groups, this genus is evidently as much at home in the West Indies as it is on the continent. While the others are preponderatingly, if not exclusively, North American, this genus is almost equally well represented north and south of the Isthmus; but something like one-third as many species occur in the West Indies as on either continent. It may be, and I think is, older than either genus of Nolineæ or of Yucceæ and younger than *Quercus,* but no very dependable or direct evidence as to this exists.

In my study of *Phoradendron,*[5] I became convinced that two very distinct groups—subgenera, if you like—make up the genus. One of these (the Boreales) includes 23 per cent of the known species; the other 77 per cent belong to the other group (Aequatoriales). The significance of the names used for these groups lies in the fact that the first centers in Mexico and the United States, only 2 of its 66 species reaching Central America and none being found in either the West Indies or South America. While none of the Aequatoriales occurs in the United States, over half of them are South American. Of this group more occur in the West Indies than in either Mexico or Central America, though the group is well represented in both of these regions.

Unlike the oaks, these mistletoes have not passed at all from Florida

into the West Indies, nor have they passed from the islands into the United States. A few very polymorphous species or scarcely segregable groups of species, like "*P. latifolium*" and "*P. rubrum*," are common to Brazil, Mexico, and the West Indies; except for these, the insular species are different from those of North America, and both differ from those of South America.

Have the insular species come from the northern or the southern mainland, or both, or have they passed to the tropical mainland in either or both directions and spread over it? As with *Yucca aloifolia*, it is not necessary to assume a land connection for the dissemination of these mistletoes. Even more than the baccate yuccas, they appear able to pass ordinary barriers, for their seeds not only are contained in edible fruits, but they are so viscidly adhesive as to be likely to be transported to considerable distances by birds which feed on the berries. As a matter of fact, the several species do not range over large regions, except for the few cases noted; but these and, in general, groups of intimately related species, occur in such a way as to lead one to believe that they may have passed into the Greater Antilles from the west or into the Lesser Antilles from South America. The greater part of the Antillean species appear to me to possess South American affinities.

Agave indicates Relationship to a successively fragmented Antillean Bridge or Spur extending southeastward from Yucatan

I have deferred until the end a discussion of the Agaveæ. Its two genera, apparently, are relatively modern. One (*Furcræa*) appears to center in South America, though it ranges from temperate Brazil to the Mexican tableland; the other (*Agave*) centers in Mexico, but ranges from Arizona to the Isthmus, extending across the continent in Mexico, and in some equivocal forms it occurs in tropical Florida and in Venezuela and Colombia.

Both genera are found throughout the West Indies: *Furcræa* in few and rather similar species; *Agave* in many species of several very distinct types. *Furcræa* appears to have entered the islands chiefly from South America. *Agave* is absent from South America except for a few species confined to the extreme northern region, the Colombian part of which show Costa Rican affinities. This genus appears to have penetrated the West Indies from the Mexican or Central American side.

Furcræas and agaves frequently are bulbiferous. Their bulbils are very tenacious of life; there is no telling, therefore, how far a species may

be carried by water. Their seeds are fairly resistant, thin, and easily blown about by the wind; but there is no reason to think that this insures dissemination to any great distance. Even on the mainland, as in the classic region of Tehuacan, the species are often narrowly limited geographically. In the West Indies this restriction is accentuated, no doubt as a result of water barriers.

The few Antillean species of *Furcræa* are suggestive. One of them (*F. cubensis*) which occurs in Cuba and Haiti is very closely related to the Yucatecan cahum (*F. cahum*).[6] The commonest and most widespread (*F. tuberosa*), which is found throughout the chain, is a close relative of the Brazilian species, which has been grown so long in Mauritius as to have acquired the name Mauritius hemp (*F. gigantea*). A third species (*F. macrophylla*), which seems to be indigenous to the Bahamas, is very like a form of northern South America. So far as these facts are indicative, they suggest immigration from both south and west; the former apparently earlier, if extent of distribution bears any relation to time.

Agave, which is represented in the West Indies by about 50 indigenous and endemic species,[7] presents these in 6 distinct types: the Antillanæ, of a dozen species, are confined to the Greater Antilles; the Bahamanæ, closely allied to the preceding, and with half as many species, are exclusively Bahamian; the Caribææ, with 15 species, are confined to the Caribbees, or Lesser Antilles. These plants are all large, of the "century plant" or "maguey" type. The southernmost islands also possess a reduced edition of this type, the Viviparæ, with five species, of which one is peculiar to Trinidad and the adjacent coastwise islands, and a sixth species of the group occurs in the coast region of Venezuela. In the northern islands, also, a smaller type occurs, represented on the Greater Antilles by five species (Antillares) and in the outlying Bahamas by two very xerophytic species (Inaguenses). The Antillanæ, Bahamanæ, Antillares, and Inaguenses of the north are clearly differentiated from the equivalent Caribææ and Viviparæ of the south.

There is no evident reason why a species of either group should not range through the entire chain of islands, like the wide-spread species or group of scarcely segregable species of *Furcræa* (*F. tuberosa*), but they do not do so. The *Agave* of Saint Thomas (*A. missionum*) is one of the Antillanæ; the *Agave* of Saint Croix, 30 miles or so away (*A. Eggersiana*), is one of the Caribææ. Less striking, but even more suggestive, are the facts that the species of either group are severally localized on a single island or on contiguous islands, and that species of any group

differ in proportion to the depth of the water barriers that separate their islands and not merely in relation to the width of these barriers.

Unless *Agave* is assumed to have originated in the West Indies, and the problem of distribution and its present bearing would remain unchanged if this scarcely plausible assumption were made, the genus must have entered the islands from the mainland. The possibility that it entered in two directions, through northern South America and also Mexico or Central America, is not excluded. In the former case the parent stock from the south would have given rise to the Caribææ and Viviparæ, and that from the north to the Antillanæ and Antillares, with their respective offshoots, the Bahamanæ and Inaguenses. The probability, however, is that it entered from the Central American region, and that its greater groups were differentiated at a relatively early date.

Either supposition calls for belief in an essentially continuous, though not necessarily direct, land connection (perhaps broken at the present Anegada Passage) between the islands and the continents, as well as between the several islands; for as they exist today the agaves of even adjacent islands do not pass back and forth.

From what I know of the representatives of this genus in the West Indies, I am compelled to believe that they were derived from the mainland at some late Tertiary or early Quaternary time when islands and continents were continuous; that then or subsequently they have spread through the chain over continuous land; that this continuity was broken by subsidence or fault when the very deep Anegada Passage was formed; and that later subsidences have caused in succession the deeper and lesser water gaps by which the Antilles are divided into groups successively more and less distinct in their agave flora.

These conclusions are in accord with some of the less sweeping indications afforded by the other groups that I have analyzed in detail, and with the general interblending of northern and southern elements in the Antillean flora; and they are not necessarily in conflict with the negative suggestion of a lack of land connection afforded by *Quercus* and the Nolineæ. They harmonize also with the fact indicated by Eggers, that the greatest break between these elements occurs where the deepest and presumably the oldest break in an Antillean bridge occurs, at the place where the Anegada Passage separates the islands Saint Thomas and Saint Croix, now under the flag of the United States.

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[5] Proceedings of the National Academy of Sciences, volume 1, 1915, page 30. W. Trelease: The genus Phoradendron, 1916, page 16.
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[7] Memoirs of the National Academy of Sciences, volume 11, 1913, page 10.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

AFFINITIES AND ORIGIN OF THE ANTILLEAN MAMMALS [1]

BY W. D. MATTHEW

(*Read before the Paleontological Society January 1, 1918*)

CONTENTS

Limitations and Relationships of West Indian mammal Faunas, Living and Extinct

IN GENERAL

The indigenous land mammals of the West Indies consist of three groups: (1) Insectivora, (2) hystricomorph rodents, (3) gravigrade edentates. No perissodactyls (horses, rhinoceroses, tapirs, etcetera), no artiodactyls (peccaries, deer, antelopes, etcetera), no proboscideans (elephants, mastodons, etcetera), no true carnivores (dogs, cats, raccoons, mustelines, bears, etcetera). Nor are there any sciuromorph, lagomorph, or myomorph rodents, shrews, moles, hedgehogs, or opossums. All these large groups, most of them abundant and varied in Tertiary North America, are wholly absent. Nor do the Insectivora, rodents, or edentates include anything at all nearly allied to any North American members of

[1] Manuscript received by the Secretary of the Society August 22, 1918.

the order or derivable from anything known to have inhabited North America in the later Tertiary.

Most of these North American groups invaded South America in the Pliocene and are part of its later fauna. In the Miocene and early Tertiary they are not found in South America, but their place is taken by a number of other groups. In place of perissodactyls, artiodactyls, and proboscideans were a number of groups of hoofed animals peculiar to Tertiary South America—the toxodonts, typotheres, litopterns, homalodontotheres, astrapotheres, pyrotheres. In place of the true Carnivora is a variety of marsupial carnivores (Borhyænidæ) paralleling the true carnivores in structure and taking their place in the fauna.[2] All of these abundant and varied groups of ungulates and pseudo-Carnivora are lacking from the Antillean fauna, nor do the rodents represent more than two or possibly three of the numerous hystricomorph rodent stocks of Miocene South America, while the edentates represent only one group of the ground-sloths, the three or four other ground-sloth groups, as well as the several kinds of armadillos and the glyptodonts, being quite unrepresented.

THE INSECTIVORA

It appears to be reasonably certain that the Antillean rodents and edentates came from South America and from Tertiary South America. Hystricomorph rodents and edentates are unquestionably South American Tertiary types, which invaded North America when the two continents were joined, toward the end of the Tertiary. The insectivores, however, are more probably derivable from North American sources;

[2] A similar but distinct group of marsupial carnivores (Dasyuridæ and Thylacinidæ) developed in Australia in absence of true Carnivora and still survives there.

NOTE.—In this paper no account is taken of animals which may have been brought to the islands by man, whether intentionally or by accident, in post-Columbian or prehistoric time. Some of these have evolved under insular conditions into races distinct enough to be recorded as species or subspecies. The majority are identical with species of North or South America, Europe, Africa, etcetera. Some are known to have been introduced; others may be so explained by reason of associations of one kind or another. The formation of distinct races, such as are classed as species by modern mammalogists, does not necessarily take many centuries under these conditions—as witness the Porto Santo (Madeira) rabbits and other instances. Some of these supposedly introduced forms may have been brought in through natural means and be truly indigenous, although not very ancient; but it is impossible to prove such cases. It seems better here to omit all this doubtful evidence and consider only the fauna that is proved to be indigenous either by occurrence in the Pleistocene cave and spring deposits, by its sharp distinctions from any continental relatives, or by the high improbability that the animal could have been transported through human agency. Dr. G. M. Allen has compiled an annotated list of the West Indian mammals which includes both introduced and indigenous types, and Dr. Thomas Barbour has done the same for the reptilia and batrachia. The evidence therein summarized will be discussed in a memoir on Cuban fossil mammals now in preparation.

for, with a single somewhat doubtful exception, the entire order of Insectivora is absent from the Tertiary faunas of South America, while they were many and varied in North America, especially in the older Tertiary. The two Antillean insectivores are not nearly related to each other, nor to any other genera of the order; they are placed in families by themselves. It has been repeatedly stated that *Solenodon* is related to the Malagasy Centetidæ, but in fact the affinity is a very distant one. *Nesophontes* is equally peculiar, and while it has some affinities with the Soricoidea (moles and shrews), they are very distant. The nearest relatives of both—collateral ancestors, perhaps—are certain imperfectly known insectivores of very primitive type in the North American Eocene and Oligocene.

THE RODENTIA

The rodents are clearly of South American affinities. They are all hystricomorphs—a group chiefly South American since the middle Tertiary (if not before). The only North American hystricomorph is the porcupine, Pleistocene and Recent, and whose ancestors have been recognized in the South American Tertiary. No traces of the hystricomorphs have been discovered in the Tertiary of North America.[3] There are certain Old World hystricomorphs, the Hystricidæ and certain Octodontidæ, and the early Tertiary Theridomyidæ of Europe have been considered ancestral to the group, but they have no significant relations to the Antillean genera and their affinities are disputed, so that they may be passed over for the present problem.

The Antillean hystricomorphs are clearly related to the South American types, but it is equally clear that the relationship is not close. There are apparently three groups. One, including *Amblyrhiza* of Anguilla, *Elasmodontomys* and *Heptaxodon* of Porto Rico, is related to the chinchillas, but not closely related. Anthony[4] places them in separate subfamilies. Miller[5] states that they are more nearly related to the extinct *Megamys* and its allies than to the living chinchillids. These genera (*Megamys, Tetrastylus,* etcetera) are found in the Entrerian, Rio Negran, Hermosan, and Araucanian formations of Argentina accompanied by a fauna which is closely related to the Pampean, but contains a few little altered survivals from the Santa Cruz Miocene and comparatively few of the North American invading types. All should, in my

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[3] Except Leidy's *Hystrix* (*Hystricops*) *venusta,* based on two teeth of doubtful affinities and uncertain geologic age.

[4] Anthony: New fossil rodents from Porto Rico. Bull. Am. Mus. Nat. Hist., vol. xxxvii, 1917, pp. 185-186.

[5] Miller: Bones of mammals from Indian sites in Cuba and Santo Domingo. Smithsonian Miscell. Coll., vol. lxvi, no. 12, 1916, p 3.

judgment, be referred to the Upper Pliocene; they are certainly much later than the Santa Cruz.

Although *Megamys* and *Tetrastylus* are without doubt more nearly related than any modern type to the Antillean chinchillids and are considerably older, they can not be regarded as ancestral. The common ancestral stock is to be found in the Santa Cruz chinchillids, all of which are of small or medium size. These Santa Cruz species are much more primitive, and the precise relationships will require more careful study.[6]

The remaining Antillean rodents are of South American type and broadly derivable from Santa Cruz rodents, but their more exact affinities are disputed and require more thorough and critical consideration and, if possible, more complete material. A thorough revision of the fossil rodent faunas of South America is an almost necessary groundwork for a correct estimate of their affinities. It is clear, however, that with the exception of *Capromys* they are not very closely related to the South American rodents, the common ancestral stock dating back probably to Pliocene or late Miocene, as Miller believes. *Capromys* (and *Geocapromys*) would seem to be an exception, being quite close to the Venezuelan *Procapromys.*

THE EDENTATA

The edentates include four quite distinct genera from Cuba and a fifth from Porto Rico, all referred to the family Megalonychidæ, but not closely related to any of the mainland forms. The largest, *Megalocnus,*[7] is about the size of a black bear; the smallest, *Microcnus,* about the size of a cat, and there are two of intermediate size, *Mesocnus,* with a rather long, narrow muzzle, and *Miocnus,* with a broad, square muzzle. The Porto Rican genus is related to *Miocnus,* both having heavy triangular tusks like the modern *Cholœpus;* the other three genera have large tusks, but of a peculiar dished shape, with a tendency to approach toward each other like the incisors of rodents. (They are not at all of the scalpriform gnawing type, however.) While these ground-sloths are sufficiently re-

[6] Miller apparently associates the Santa Cruz fauna of southern Patagonia with the very different and much later Entrerian fauna of northern Argentina, as he speaks of the two as though they were essentially one fauna, and refers to the "enormous extinct Pagatonian rodents" as the nearest relatives of the Antillean chinchillids. The largest Santa Cruzian rodents are species of *Perimys,* which is not nearly related to the Antillean genera. Most of the species are quite small. As between the Santa Cruz and the Hermosan (Pliocene) group of faunas, the tendency to rapid increase in size and specialization of numerous phyla is very marked, and is further emphasized in the Pampean (Pleistocene) group of faunas.

[7] *Megalocnus,* Leidy, 1868. Proc. Acad. Nat. Sci. Phila., 1868, p. 179.

Microcnus, etc., La Torre and Matthew, 1915. Bull. Geol. Soc. Am., vol. xxvi, p. 152 (names only; descriptions have been reserved pending the securing of more complete and better associated skeleton material).

lated to the North American genus *Megalonyx* to be placed in the same subfamily, they are quite evidently not descended from it, but contemporaneous specializations from the primitive Megalonychidæ of the South American Miocene, as represented in the Santa Cruz fauna. Among the known genera of this fauna there is only one, *Eucholœops* (including *Megalonychotherium*), which can be regarded as ancestral either to the Cuban ground-sloths or to *Megalonyx*. The others all have the caniniform teeth much reduced or vestigial and in series with the cheek teeth. To the best of my judgment, the anatomical evidence is not decisive as to whether the five Antillean genera are descended from one or from two or more nearly allied Upper Miocene or Lower Pliocene genera, but leads to the conclusion that the common ancestor or ancestors was very close to or identical with the Upper Miocene ancestor of *Megalonyx*, and was either the genus *Eucholœops* or one or more genera closely allied thereto. The Antillean genera represent, therefore, only the megalonychine division of the Megalonychidæ. The other families of ground-sloths—Mylodontidæ, Scelidotheridæ, and Megatheriidæ—are not found; nor are there any armadillos, glyptodonts, or anteaters.

BATS AND BIRDS

In addition to the terrestrial mammals, bats are numerous in the cave deposits, and a number of birds, lizards, crocodiles, and turtles have been found at the Ciego Montero locality and elsewhere.

Concerning the bats, there is very little to say. Most of them are nearly allied to or identical with species now living on the islands. The Antillean bats include a number of peculiar genera, besides others common to the continental parts of tropical America. Their relations are much the same as those of the birds, and in either case it is obvious that the intervening seas would act as a hindrance to migration, but not as an absolute barrier, and would be more of a hindrance in some groups than in others. The result would be the presence of a number of peculiar types, preserved by relative isolation and specialized in adaptation to the peculiarities of their habitat, along with other widely ranging forms closely allied to or identical with those of the mainland. The distribution of the birds has been carefully studied by Chapman and others.

REPTILES

The distribution of the lizards has been recently studied by Dr. Thomas Barbour, and his conclusions as to the paleogeography are sharply at variance with mine, owing to different methods of interpreting the data. I shall not take this part of the problem up at present.

The fossil crocodiles have been examined by Dr. Barbour, who informs me that they are all referable to *Crocodilus rhombifer,* a species still living on the island of Cuba.[8] The origin of this species might be either North or South American; but too little is known of the phylogeny and distribution of the Tertiary Crocodilia for any conclusions to be drawn as to the time or method of its arrival.

The fossil chelonians have not been carefully studied, but they include two species—one a giant tortoise, *Testudo cubensis* Leidy, which, like the giant tortoises of the Galapagos and Indian Ocean islands, has the carapace much thinned out, so that the plates are apparently more or less discontinuous. There is one North American Pliocene species, *T. pertenuis* Cope, from Texas which has a remarkably thin carapace, but apparently not discontinuous. The precise significance of this species in the paleogeographic problem must also await more careful study. The genus *Testudo* occurs sparingly in South America, and is recorded as a fossil in the Pliocene and Pleistocene formations—not earlier, so far as I know. On the other hand, species of *Testudo* are the most abundant of fossils in the Oligocene to Pliocene formations of North America; in the Pleistocene and Recent their range is restricted to the Southern States and Mexico. The indications point, therefore, preferably to North American origin for this Cuban tortoise, although not decisively.

The second fossil chelonian is one of the Emydidæ, or marsh-turtles; it appears to be a species of *Graphemys,* probably the same as the still existing Cuban species, which is said to be a close ally of *G. scripta* of the Southeastern States. Whether the two are specifically distinct has been questioned. The discovery of this species (if it be the same) fossil in the Ciego Montero locality removes any doubt as to its being indigenous to the island, as it carries it back into the Pleistocene, and probably to a time before the arrival of man. Its close relationship with *G. scripta* and limitation to the western islands, Cuba and Haiti, is a strong indication of its having come from Florida, and the time of its arrival probably would be not earlier than Pleistocene or at most late Pliocene.

Summary of Affinities and probable Origin of the vertebrate Groups

Summing up the indicated sources of the fossil and recent vertebrate fauna, we find it to be as follows:

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[8] Leidy's *Crocodilus pristinus* (1868, l. c.) was based upon a vertebra not distinguished from *C. rhombifer.* The skulls obtained by La Torre and Brown represent, in Doctor Barbour's opinion, a series of growth stages of the modern species, the largest much exceeding any modern specimens. Part of a skeleton associated with one of the largest skulls equals or exceeds Leidy's type of *pristinus* in size.

1. The Insectivora, *Solenodon* and *Nesophontes,* of very ancient arrival, probably early Tertiary, and apparently of North American origin.

2. The ground-sloths, ***Megalocnus, Mesocnus, Miocnus, Microcnus*** in Cuba and *Acratocnus* in Porto Rico, of moderately ancient arrival, probably late Miocene or early Pliocene, and of undoubted South American origin. The rodents, with the exception of *Capromys,* fall also into this category.

3. The peculiar groups of birds, bats, and lizards are also no doubt of comparatively ancient arrival, but their source is unknown, as we know nothing of the Tertiary distribution of related groups on the mainland. The modern distribution of such related groups can not be relied on, for we know that among terrestrial mammals various groups which are today exclusively or chiefly Neotropical were Nearctic until the end of the Tertiary and unknown in South American faunas until the late Pliocene. Presumably corresponding changes in distribution have occurred among the bats, birds, and reptiles, but we have no records as to what groups were affected. The Cuban crocodile may also be placed in this category.

4. Of the two chelonians the giant tortoise may be placed as more probably of North American than of Central or South American origin, but its time of arrival can hardly be estimated until its relations to the continental Tertiary species are known. The terrapin is almost certainly of North American origin, derived from the Southeastern States, and of comparatively late arrival, probably late Pliocene or Pleistocene.

5. *Capromys* and *Geocapromys* are undoubtedly of South American derivation, like the other rodents; but, so far as may be judged from their comparatively near affinity with the Venezuelan *Procapromys,* are of later arrival, perhaps late Pliocene or Pleistocene.

It appears, therefore, in sum, that the vertebrate fauna, fossil and recent, represents only a few selections from the continental faunas of either North or South America; that it falls into several groups of diverse origin, and judging from their degree of differentiation, of diverse times of arrival.

Is the incomplete and unbalanced Character of the Fauna Real or only Apparent?

In the absence of hoofed animals, which form the greater part of all continental faunæ, in the tendency of races normally of small size to assume relatively large size and importance, in the relative fragility, so to speak, of the fauna, leading to its early disappearance when man invades the region—in many further points of detail—it parallels the faunas of those islands which lie beyond the continental shelf, and differs

from those islands which lie within the shelf. In particular, the parallelism with the Madagascar fauna is made much closer by the recent discoveries. On the other hand, the contrast with the fauna of continental islands such as Borneo or Sumatra is a marked one. On these islands the fauna, although considerably specialized by isolation in Borneo, less so in Sumatra, is a fairly representative one. It includes all or nearly all of the important mammalian groups of the mainland save those which there is reason to believe are of too recent arrival or of unsuitable habitat to be present.

It may be objected that this difference is merely apparent; that the Pleistocene fauna of the Antilles was really of continental character, but because they are islands and not continents, it has been easily exterminated by man, and that the cave and spring deposits present only two distinct and very limited facies, not including the ungulates, carnivores, etcetera, which have been present. The best reply to this objection is to test it by comparison. Sumatra or Java are islands of comparable size to Cuba; Borneo is larger; Formosa or Hainan are comparable to Porto Rico. In none of these islands has the indigenous fauna been wiped out to anything like the extent necessary to obliterate its continental character, although all have been inhabited by man for a much longer time and in much larger numbers than the Antilles. The indigenous faunas of Great Britain or Ireland are far from exterminated, in spite of the great density of population and of modern civilization.

Nor can we assume that a cave or a spring fauna is so limited in its facies as to disguise a continental fauna type. The faunas of numerous caves in Europe and North America have been examined, and wherever any considerable collection is obtained it is clearly representative of the continental type. Spring or bog faunas sometimes contain little except hoofed animals, but I never heard of one in which hoofed animals and carnivora were absent. I can not escape from the conclusion that the Pleistocene fauna of Cuba was not a normal fauna, but deficient in most of the more abundant groups and composed of a selection of a very limited number of types which had expanded to a disproportionate variety and importance, owing to the absence of the rest of the fauna.

Conclusions as to former geographic Relations and Manner of Colonization

As to the diverse origin of the several groups and the varying time during which they have been isolated on the islands, I have stated my interpretation of the evidence. I do not feel, however, that evidence of this sort leads to positive and certain conclusions.

As to the former connection of the Antilles with each other and with the mainland, my conclusions with the proviso just stated are as follows:

1. That the Greater Antilles have probably been united with each other, as far east as the Anguilla bank, in the late Tertiary or Pleistocene. This I conclude from the near affinity of representative species of the same or closely allied genera and the general similarity of the fauna, so far as known, in the different islands.

2. That they have not at any time during the Tertiary been united with North America. If they had been we should find North American ungulates, rodents, carnivores, etcetera, differentiated in accord with the length of subsequent isolation, but of clearly recognizable affinities, and it would be a balanced or representative fauna. We might object that such a fauna had perhaps existed, but been wiped out by subsequent submergence. But the presence of *Solenodon* and *Nesophontes* negatives that, for they represent a very ancient survival, and if there had been a representative fauna it is hardly credible that submergence would have spared just two insectivores and destroyed all the rest of the fauna.

3. That they probably have not been connected with South America, either via the Lesser Antilles or via Central America, during the Tertiary; for if they had the fauna should be of continental South American type, with South American ungulate groups, marsupial carnivores, and a full representation of the rodents, edentates, etcetera.

4. The mammalian fauna appears to me to be reducible to perhaps three primary rodent stocks, one or more primary ground-sloth stocks, and two Insectivora. These I conceive to have arrived at various times during the Tertiary, the rodents and ground-sloths from South or Central America, the insectivores from North America, by accidents of transportation, of which the most probable for the mammals would perhaps be the so-called "natural rafts" or masses of vegetation dislodged from the banks of great rivers during floods and drifted out to sea. The probabilities of this method I have elsewhere discussed.[9] For birds and bats, for the smaller reptiles, amphibians, fishes, and invertebrates, the problem of oversea transportation is a much simpler one.[10] That successful colonization in this way can occur is shown by their presence on nearly all oceanic islands; for it will hardly be maintained by reasonable men that every oceanic island has been joined to the mainland and has been continuously above water since its separation. Obviously, the larger the island and the nearer to continental land, the more often such colonization will occur.

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[9] Matthew: Climate and evolution. Annals N. Y. Acad. Sci., vol. xxiv, 1915, p. 206.

[10] Tropical storms, as Wallace pointed out years ago, probably play a principal part in transportation of very small animals or their eggs. Mammals could hardly be carried that way nor survive if they were.

5. The geology of the Caribbean region appears to me to afford no positive evidence against union of the Antilles either with South America or Central America; but neither does it afford any evidence that there ever was such union. Undoubtedly there is a line of disturbance and uplift along the Lesser Antilles, and another stretching through Haiti and Jamaica to Nicaragua; but evidence of similar and contemporaneous upheavals and similar sedimentation in two portions of this line of disturbance that are now separated by abyssal depths does not in the least prove that the intervening depths were formerly continuous land bridges. They may have been, but I do not see how any geologic evidence can prove that they were so. If we have evidence from some other source that there must have been a land bridge somewhere, then these lines of disturbance show its most probable location. That is all.

Land union with Florida appears to be distinctly against the geologic evidence, as in this region we have extensive flat-lying Tertiary marine and littoral formations which indicate that there has been very slight movement during the Tertiary, and that the present limits of the continental shelf represent probably the extreme extension of the land in the Pleistocene. Dall has shown the evidence very clearly in the case of Florida. Apparently the conditions in Yucatan are partly similar, but Vaughan has shown that its tectonic relations to the Antillean ridges are more favorable to a former union.

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